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THE ALBANY WATER FILTRATION PLANT.

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[*Presented September 13, 1899.*]*

HISTORICAL.

Albany, N. Y., was originally supplied with water by gravity from reservoirs on small streams west and north of the city. In time, with increasing consumption, the supply obtained from these sources became inadequate, and an additional supply from the Hudson River was introduced. The water was obtained from the river through a tunnel under the Erie Basin, and a pumping station was erected in Quackenbush Street to pump it to reservoirs, one of which served also as the distributing point for one of the gravity supplies. The intake, which was used first in 1873, drew water from the river opposite the heart of the city. In recent years, the amount of water drawn from this source has greatly exceeded that obtained from the gravity sources.

Some of the city sewers enter the river above this intake, but most of them are below it. In times of flood, the water thus obtained was polluted by the sewage of only a few of the city sewers; at low-water stages, however, owing to the tidal currents, the water contained much sewage, which was carried upstream to the intake, and the sewage of the city was thus present, in very considerable amount, in its own water supply.

In addition to the pollution from local sources, the river receives

*Presented as an informal talk at the Syracuse convention. In its present form the paper is abstracted by the editor from one read by Mr. Hazen before the American Society of Civil Engineers on January 3, 1900. The cuts have been electrotyped, by permission of the American Society of Civil Engineers, from the paper just referred to, except those on Plate IV, which are from Mr. Hazen's book on Filtration, by permission of John Wiley & Sons.

the sewage of Troy and the surrounding cities, seven or eight miles above, and that of Schenectady, Utica, Rome, and many other places farther away.

Under these conditions the typhoid fever death rate in Albany was excessive. Prof. W. P. Mason, of Troy, made a report in 1885 upon the quality of the water, in which he stated that the water as then used was a source of disease, and should be abandoned at the earliest practicable date. Following this, an attempt was made to secure a ground-water supply, but without results. Studies were then made for gravity sources of supply, mentioned in the reports of the Board of Water Commissioners for the years 1891 to 1893; but the necessary legislation was not obtained.

In 1896 the Board investigated methods of purifying the present supply. The matter was studied by the Board and by its Superintendent, Mr. George I. Bailey, and in January, 1897, the author was engaged to examine the studies which had been made, and to report upon the projects presented. His report recommended the general scheme previously outlined by the Superintendent, namely, to abandon the present intake, and to establish a new one about two miles farther up the river, at a point above all the local sources of pollution, and to pump the water by low-lift pumps to a settling basin, from which it would flow to sand filters, and thence through a pure-water conduit to the present pumping station in Quackenbush Street.

The report was accepted, the recommendations adopted, and the necessary funds were provided; and, in July, 1897, the preparation of plans was begun.

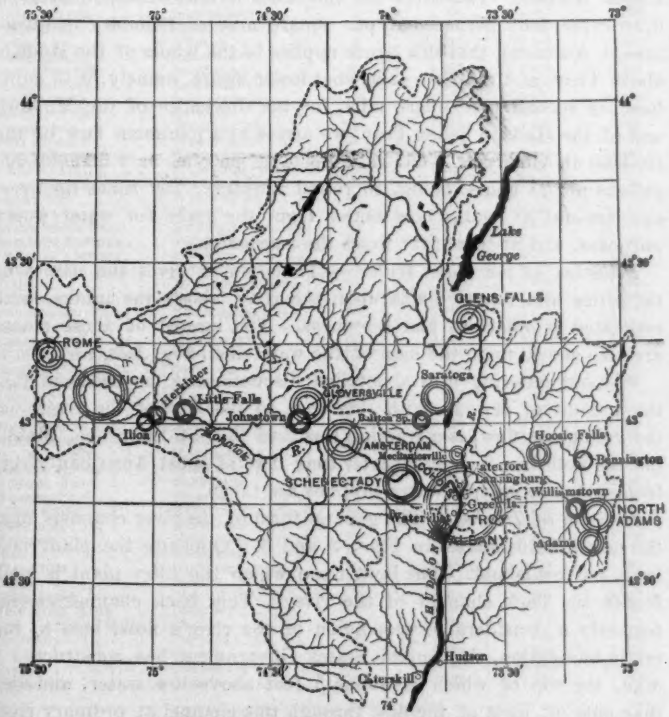
As the pure-water conduit was to be placed in the Erie Canal, and as the work of constructing it necessarily had to be done during the season of closed navigation, plans for this part of the work were prepared first. The contract was let in November, 1897, and that part of the work under the canal was completed before navigation opened, May 1, 1898.

The contract for the filters and sedimentation basin was awarded in February, 1898, and work was commenced in April; but, owing to various reasons connected with the installation of a very elaborate contractors' plant, work was not pushed actively until August, 1898. Contracts for the pumping machinery, and for the pumping station and intake, were let in June and August, 1898, and the work was carried out during the fall and winter. Construction was sufficiently

advanced so that a part of the plant was put in operation on July 27, 1899. The old intake was closed on September 6, 1899, since which time no unfiltered river water has been pumped to the city.

SOURCE OF SUPPLY.

The source of supply is the Hudson River, which, at the point of intake, has a drainage area of 8 240 square miles. Of this, 4 570



WATERSHED OF HUDSON RIVER ABOVE INTAKE

Note:- Circles show population in 1890, 1890, and estimated population for 1900. A single circle indicates no growth or very slow growth.

SCALE

0 10 20 30 40 50 MILES

0 10 20 30 40 50 60 70 80 90 100 KILOMETERS

FIG. 1.

square miles are tributary to the Hudson above Troy, 3 502 are tributary to the Mohawk, and 168 are tributary to the Hudson below the Mohawk.

No gagings of the river at this point are available. The average annual flow of the stream probably amounts to at least 1 000 000 gallons per square mile per day, or over 8 000 000 000 gallons per day. The minimum flow is only a small fraction of this amount. Mr. George W. Rafter, who has made a study of the flow of the Upper Hudson,* estimates the minimum flow at Mechanicsville at 0.24 cubic foot per second per square mile of tributary drainage area. Assuming that this figure applies to the whole of the Hudson above Troy, and taking a somewhat lower figure, namely, 0.15 cubic foot per second per square mile, for the discharge of the Mohawk and of the Hudson below Troy, we arrive at a minimum flow of the Hudson at Albany of 1 657 cubic feet per second, or 1 060 000 000 gallons per 24 hours, being, in round numbers, 100 times the average amount of water now taken from the river for water works purposes, and at least fifty times the maximum.

Pollution of the Raw Water. — Table No. 1 gives the names of the cities and larger towns upon the river above the intake, with estimated populations and distances. The largest of these places are also shown upon the map of the watershed, Fig. 1.

Without entering into a detailed discussion, it may be said that the amount of sewage, with reference to the size of the river and the volume of flow, is a fraction less than that at Lawrence, Mass., but the pollution is much greater than that of most American rivers from which municipal water supplies are taken.

Position of Intake. — The general form of the river channels near the new plant is shown in Figs. 2 and 3. Opposite the plant is a long, narrow island. The land upon which the filter plant is built fronts the back channel of the river. This back channel carried formerly a considerable proportion of the river's flow, but, to improve navigation, the United States Government has constructed a dike, the top of which is about 5 feet above low water, and this dike cuts off most of the flow through this channel at ordinary river stages. At flood stages the dike is overtopped, and the channel takes a large amount of water.

The question arose, whether to build an intake across the back

* Report of the State Engineer and Surveyor for 1895, p. 119.

TABLE No. 1.—Cities, Towns, and Villages on the Watershed of the Hudson River above Albany, with Populations of 1 000 and Over.

Place.	County.	Approximate distance above intake. Miles.	Population in		
			1880.	1890.	1900. (Estimated.)
Troy	Rensselaer	4	56 747	60 956	65 470
Watervliet	Albany	4	8 820	12 967	19 040
Green Island	Rensselaer	5	4 100	4 463	4 788
Waterford	Saratoga	9	1 822	1 822	1 822
Cohoes	Albany	8	19 416	22 509	26 450
Lansingburg	Rensselaer	8	7 432	10 550	14 980
Mechanicsville	Saratoga	19	1 265	2 679	5 358
Schaghticoke	Rensselaer	27	1 258	1 258	1 258
Schenectady	Schenectady	28	13 655	19 002	26 450
Schuylerville	Saratoga	32	1 617	1 387	1 190
Greenwich	Washington	39	1 231	1 663	2 247
Fort Edward	Washington	43	4 680	4 424	4 182
Hoosic Falls	Rensselaer	44	4 530	7 014	10 860
Amsterdam	Montgomery	44	9 466	17 336	31 730
Cambridge	Washington	45	1 482	1 598	1 723
Sandy Hill	Washington	46	2 487	2 895	3 371
Glens Falls	Warren	49	4 900	9 509	18 450
South Glens Falls	Saratoga	49	1 083	1 606	2 387
Saratoga Springs	Saratoga	51	8 421	11 975	17 010
Ballston Springs	Saratoga	51	3 011	3 527	4 131
Fultonville	Montgomery	54	881	1 122	1 429
Fonda	Montgomery	54	944	1 100	1 500
Johnstown	Fulton	56	5 013	7 768	12 040
Bennington, Vt.	Bennington	56	3 971	3 971	3 971
Gloversville	Fulton	58	7 133	13 864	26 930
Canajoharie	Montgomery	63	2 013	2 089	2 168
Williamstown, Mass.	Berkshire	63	3 894	4 221	5 250
Corinth	Saratoga	64	510	1 223	2 444
North Adams, Mass.	Berkshire	68	10 191	16 074	25 340
Luzerne	Warren	68	468	868	1 610
Schoharie	Schoharie	68	1 188	1 028	889
Fort Plain	Montgomery	69	2 443	2 864	3 358
Middleburg	Schoharie	73	1 123	1 139	1 155
St. Johnsville	Montgomery	74	1 072	1 263	1 488
Cobleskill	Schoharie	74	1 222	1 822	2 717
Adams, Mass.	Berkshire	75	5 591	9 213	15 181
Warrensburg	Warren	82	748	893	1 073
Little Falls	Herkimer	82	6 910	8 783	11 160
Herkimer	Herkimer	90	1 353	1 353	1 353
Mohawk	Herkimer	91	1 441	1 896	2 264
Ilion	Herkimer	98	3 711	4 057	4 436
Frankfort	Herkimer	95	1 085	2 291	4 582
Utica	Oneida	104	33 914	44 007	57 090
Whitesboro	Oneida	107	1 370	1 663	2 018
New York Mills	Oneida	108	1 195	1 195	1 195
New Hartford Mills	Oneida	.....	710	912	1 171
Oriskany	Oneida	111	597	860	1 239
Clinton	Oneida	121	1 236	1 260	1 303
Rome	Oneida	121	12 194	14 991	18 430
Waterville	Oneida	127	1 734	1 734	1 734
Total, not including rural population			272 838	354 672	479 415
Per square mile			33	43	59

channel and the island to the main channel of the river, or to take water from the more convenient back channel. Each point had its advantages. To determine the relative character of the water,

TABLE No. 2.—Bacterial Examinations of Water from Main Channel and from Back Channel at Proposed Points of Intake.

Date.	Hour.	Approximate state of tide.	Back Channel.		Main Channel.	
			Turbidity.	Bacteria.	Turbidity.	Bacteria.
1898.						
March 24 . .	3.00 P.M.	Low tide	. . . . .	2 250	. . . . .	. . . . .
April 13 . .	11.00 A.M.	Rising	. . . . .	1 227	. . . . .	2 889
20 . .	7.15 A.M.	High	. . . . .	1 970	. . . . .	. . . . .
	8.00 ,,	High	. . . . .	. . . . .	. . . . .	2 165
June 8 . .	12.00 M.	High	0.04	400	. . . . .	2 200
20 . .	1.30 P.M.	Falling	0.09	350	. . . . .	825
24 . .	7.00 A.M.	Low	0.03	1 000	0.04	1 040
	9.20 ,,	Rising	0.03	760	0.04	1 120
	11.40 ,,	Nearly high . .	0.03	600	0.04	1 040
	2.00 P.M.	After high . . .	0.03	300	0.04	4 000
	4.20 ,,	Falling	0.03	1 400	0.04	5 200
	6.40 ,,	Low	0.03	640	0.04	3 600
30 . .	2.00 P.M.	Nearly high . .	. . . . .	. . . . .	0.03	2 040
	2.30 ,,	High	0.04	860	. . . . .	. . . . .
July 7 . .	9.00 A.M.	High	. . . . .	. . . . .	0.03	4 360
	10.00 ,,	After high . . .	0.04	360	. . . . .	. . . . .

examinations were made by Dr. George Blumer, of the Bender Hygienic Laboratory, of Albany. The most important results of these examinations are shown in Table No. 2. The results are normal, and represent the condition of the water as it would be ordinarily. They show, in a general way, that the water in the back channel was considerably better than that in the main channel. Occasionally, there was but little difference, and this would always be the case when the river was in flood. At no time was the water in the back channel materially worse than in the main channel.

One of the city sewers enters the river at a point a short distance from the outlet of the back channel, and there was a possibility that sewage therefrom would be carried up this channel by flood tides. On the other hand, the water in the main channel had come directly from the Troy sewers, while that in the back channel was more or less completely cut off from the main current, and was moved back and forth by the tides, and opportunities for natural purification were present in greater degree than in the main channel. These conditions, apparently, more than offset the possible admixture of fresh sewage.

DESCRIPTION OF PLANT.

The filter plant, and all structures connected therewith, are shown

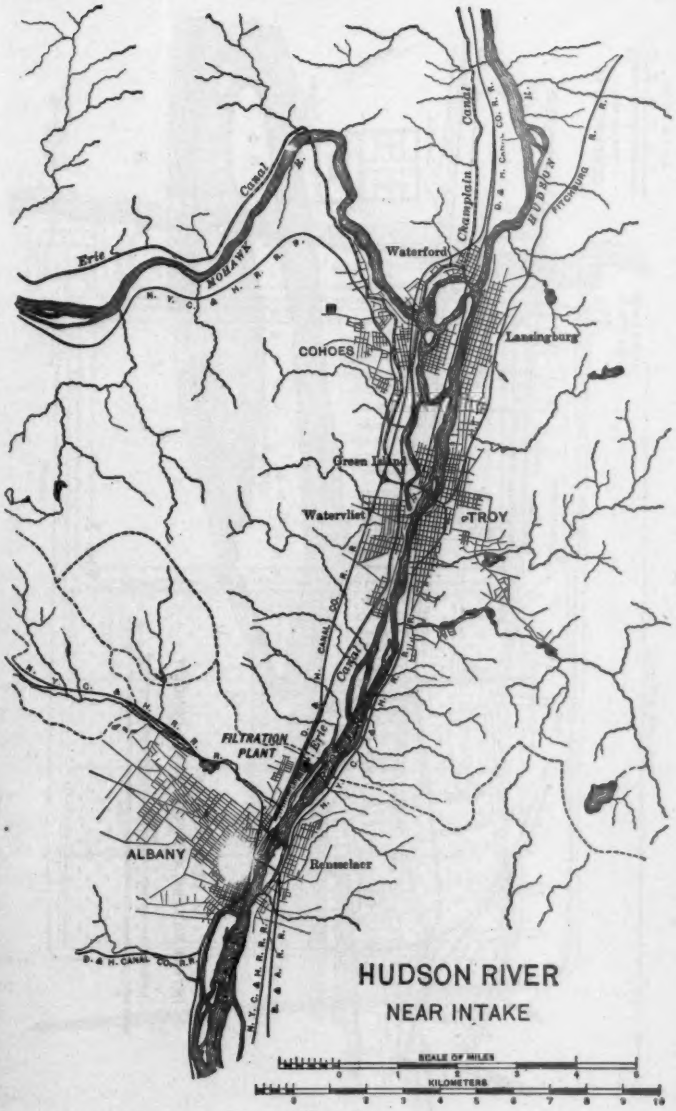

Erie Canal
MOHAWK
N. Y. C. & H. R. R. R.
Champlain Canal
D. & H. Canal Co. R. R.
Troy & Boston R. R.
Fitchburg R. R.
Waterford
COHOES
Lansingburg
Green Island
Watervliet
TROY
D. & H. CANAL CO.
Erie Canal
FILTRATION PLANT
ALBANY
Rensselaer
D. & H. CANAL CO. R. R.
N. Y. C. & H. R. R. R.
B. & A. R. R.
HUDSON RIVER
NEAR INTAKE
SCALE OF MILES
0 1 2 3 4 5
KILOMETERS
0 1 2 3 4 5 6 7 8 9 10

FIG. 2.

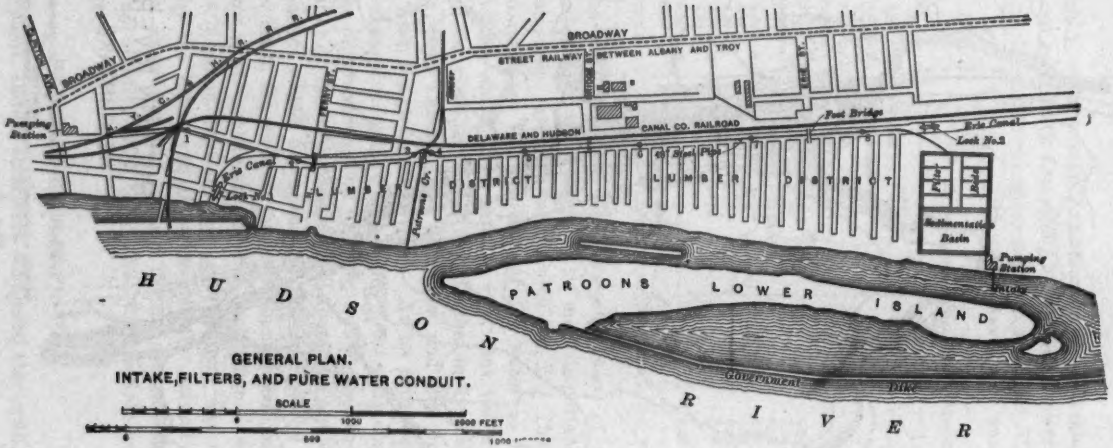

BROADWAY
BROADWAY
STREET RAILWAY BETWEEN ALBANY AND TROY
DELAWARE AND HUDSON CANAL CO. RAILROAD
Pumping Station
Erie Canal
Lock No. 1
Fort Bridge
Erie Canal
Lock No. 2
Pilot
Pilot
Sedimentation Basin
Pumping Station
Intake
L U M B E R D I S T R I C T
L U M B E R D I S T R I C T
H U D S O N
PATROONS
LOWER ISLAND
GOVERNMENT DIKE
R I V E R
GENERAL PLAN.
INTAKE, FILTERS, AND PURE WATER CONDUIT.
SCALE
0 1000 2000 FEET
0 500 1000 metres

FIG. 3.

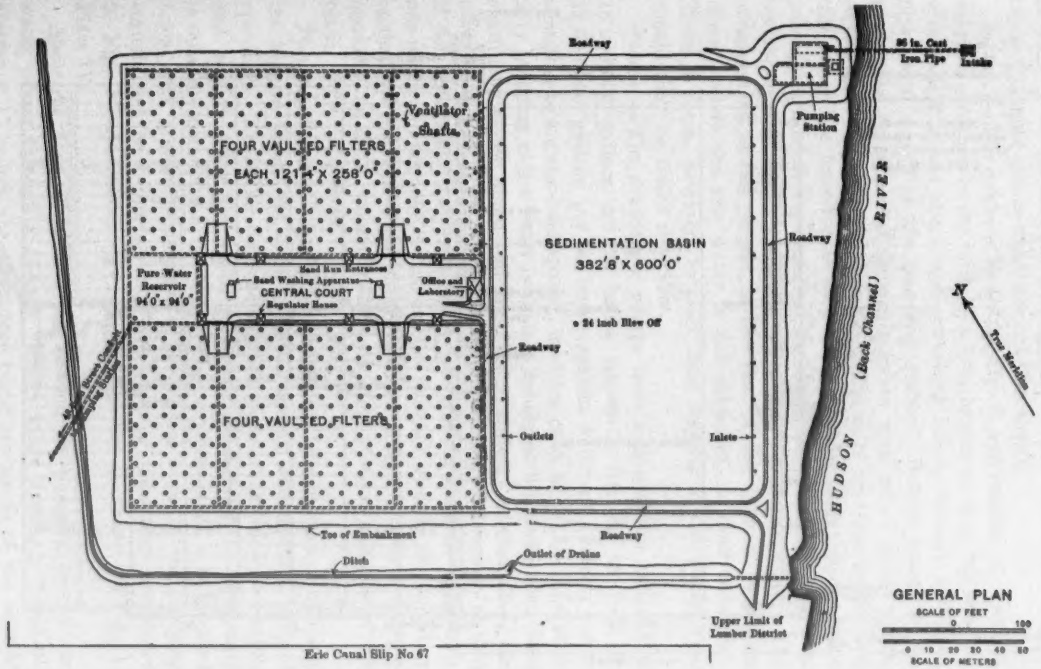

Roadway
36 in. Cast Iron Pipe
Intake
Pumping Station
Ventilator Shafts
FOUR VAULTED FILTERS
EACH 121'-0" X 258'-0"
SEDIMENTATION BASIN
382'-6" X 600'-0"
Roadway
RIVER
HUDSON (Back Channel)
Pure Water Reservoir 94'-0" x 94'-0"
Sand Run Entrance
Sand Washing Apparatus
CENTRAL COURT
Regulator House
Office and Laboratory
24 inch Blow Off
Roadway
FOUR VAULTED FILTERS
Outlets
Inlets
Toe of Embankment
Roadway
Ditch
Outlet of Drains
Upper Limit of Lumber District
Erie Canal Slip No 67
N
True Meridian
GENERAL PLAN
SCALE OF FEET
0 100
0 10 20 30 40 50
SCALE OF METERS

FIG. 4.

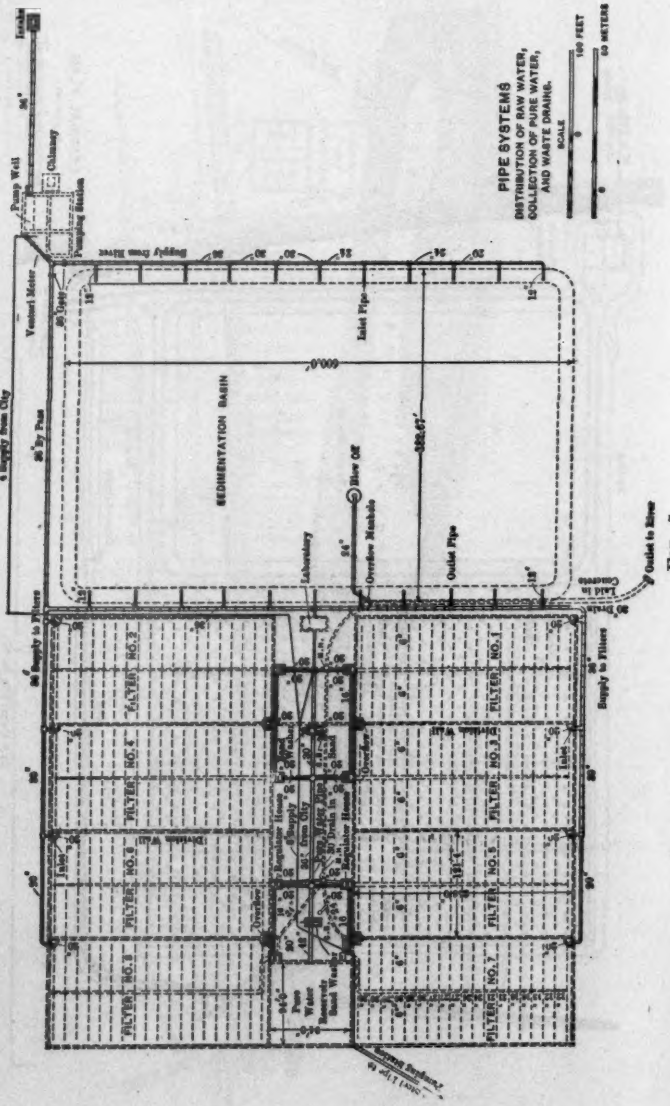

PIPE SYSTEMS
DISTRIBUTION OF RAW WATER,
COLLECTION OF PURE WATER,
AND WASTE DRAINS.
SCALE
100 FEET
50 METERS
SEDIMENTATION BASIN
Inlet Pipe
Outlet Pipe
Blow Off
Overflow Manhole
Laboratory
Pump Well
Chimney
Pumping Station
Supply from City
Supply from River
Vertical Meter
Dry Pipe
Supply to Filters
Outlet to River
Lake Ontario
FILTER NO. 1
FILTER NO. 2
FILTER NO. 3
FILTER NO. 4
FILTER NO. 5
FILTER NO. 6
FILTER NO. 7
FILTER NO. 8
Regulator House
Pure Water Reservoir
Waste Water Reservoir
Inlet
Outlet
Drain
Overflow

FIG. 5.

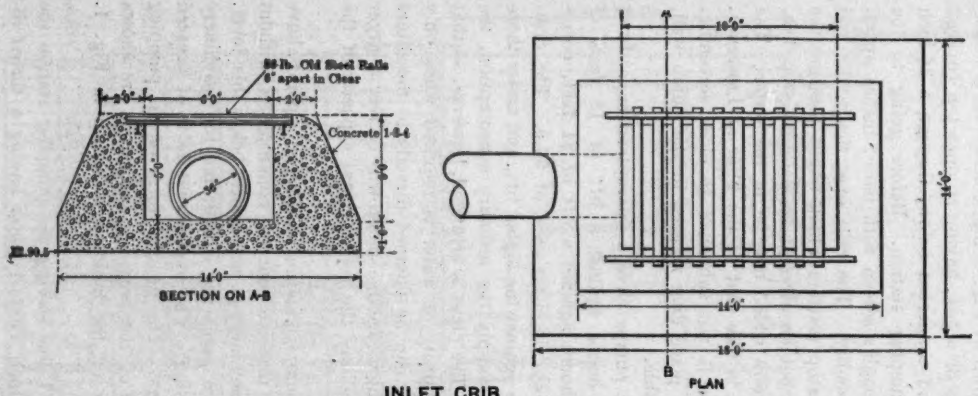
in Figs. 3 to 14, and this description, for the most part, will be limited to those points which are not thus shown.

Intake. — The intake is shown by Fig. 6, and consists of a simple concrete structure in the form of a box, having an open top covered with rails 6 inches apart, and connected below, through a 36-inch pipe, with a well in the pumping station. Before going to the pumps the water passes through a screen with bars 2 inches apart, so arranged as to be raked readily. The rails over the intake and this screen are intended to stop matters which might obstruct the passageways of the pumps, but no attempt is made to stop fish, leaves, or other floating matters which may be in the water. The arrangement, in this respect, is like that of the filter at Lawrence, Mass., where the raw water is not subjected to close screening. There is room, however, to place finer screens in the pump well, should they be found desirable.

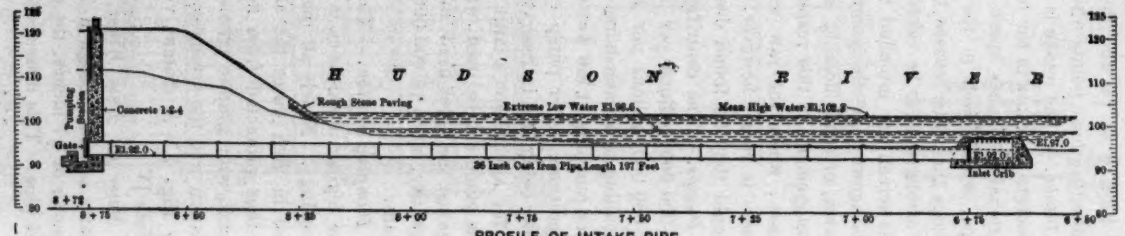
Pumps. — The centrifugal pumps have a guaranteed capacity of 16 000 000 gallons per 24 hours against a lift of 18 feet, or 12 000 000 gallons per 24 hours against a lift of 24 feet, corresponding to a water-horse-power, in either case, of 50.5. The ordinary pumping at low water is against the higher lift, and under these conditions either pump can supply the ordinary consumption, the other being held in reserve. The plant is arranged, however, so that if for any reason a large quantity of water is required when only one pump can be used, water can be pumped directly to the filters against the lower head, in which case one pump will deliver a larger quantity, up to 16 000 000 gallons, the full nominal capacity of the plant.

Pumping Station. — The pumping station building, to a point above the highest flood-level, is of massive concrete construction, without openings. Nearly all the machinery is necessarily below this level, and in high water the sluice gates are closed, and the machinery is thus protected from flooding. The superstructure is of pressed brick, with granite trimmings. The general form of the pumping station and the arrangement of the pumping machinery are shown in Fig. 7. A distant view of the building is shown in Fig. 1, Plate IV.

Meter for Raw Water. — Upon leaving the pumping station the water passes through a 36-inch Venturi meter having a throat diameter of 17 inches, the throat area being two ninths of the area of the pipe. This meter records the quantity of water pumped, and is



INLET CRIB



PROFILE OF INTAKE PIPE

FIG. 6.

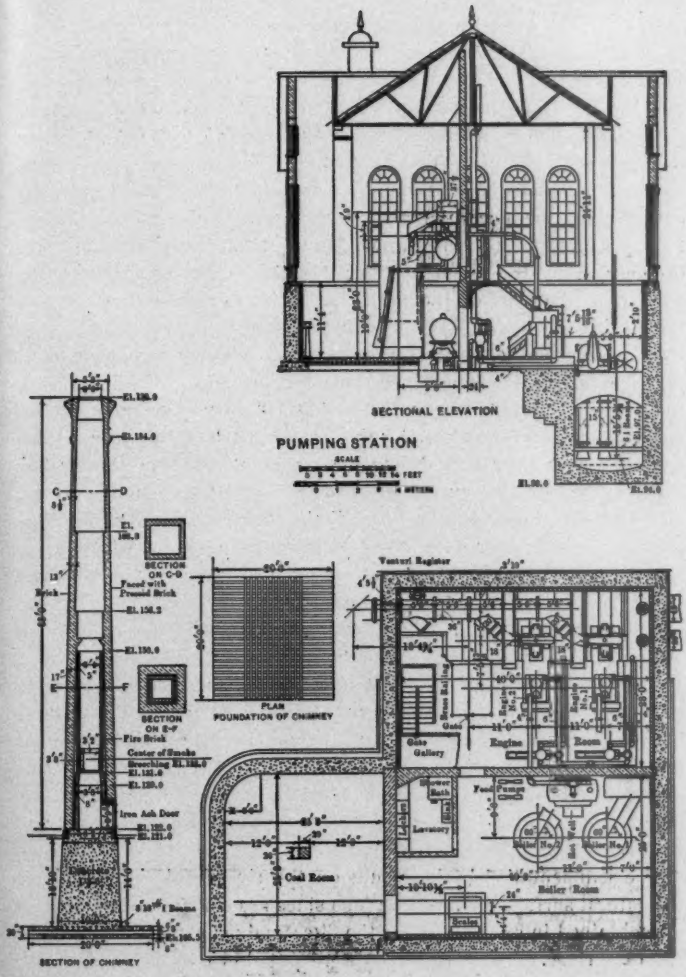

SECTIONAL ELEVATION
PUMPING STATION
SCALE
FEET
METERS
El. 130.0
El. 124.0
SECTION ON C-D
Faced with Pressed Brick
El. 156.2
El. 130.0
SECTION ON E-F
Fire Brick
Center of Smoke Breeching El. 122.0
El. 121.0
El. 120.0
Iron Ash Door
El. 120.0
El. 121.0
El. 105.5
SECTION OF CHIMNEY
PLAN FOUNDATION OF CHIMNEY
Venturi Register
Engine Room
Gate Gallery
Coal Room
Boiler Room
Feed Pumps
Boilers No. 1
Boilers No. 2
Scales

FIG. 7.

also arranged to show on gages in the pumping station the rate of pumping.

Aeration. — After leaving the meter, the water passes to the sedimentation basin through eleven outlets. These outlets consist of 12-inch pipes on end, the tops of which are 4 feet above the nominal flow line of the sedimentation basin. Each of these outlet pipes is pierced with 296 $\frac{3}{8}$-inch holes extending from 0.5 to 3.5 feet below the top of the pipe. These holes are computed so that when 11 000 000 gallons of water per day are pumped, all the water will pass through the holes, the water in the pipes standing flush with the tops. The water is thus thrown out in 3 256 small streams, and becomes aerated. When a larger quantity is pumped, the excess flows over the tops of the outlet pipes in thin sheets, which are broken by the jets.

Regarding the necessity for aeration, no observations have been taken upon the Hudson River, but, judging from experience with the Merrimac, at Lawrence, where the conditions are in many respects similar, the water is, for the greater part of the year, nearly saturated with oxygen, and aeration is not necessary. During low water in summer, however, there is much less oxygen in the water, and at these times aeration is a distinct advantage. Further, the river water will often have a slight odor, and aeration will tend to remove it. The outlets are so arranged that they can be removed readily, if they are not found necessary.

Sedimentation Basin. — The sedimentation basin has an area of 5 acres and is 9 feet deep. To the overflow, it has a capacity of 14 600 000 gallons, and, to the flow line of the filters, 8 900 000 gallons. There is thus a reserve capacity of 5 700 000 gallons between these limits, and this amount can be drawn upon, without inconvenience, for maintaining the filters in service while the pumps are shut down. This allows a freedom in the operation of the pumps, which would not exist with the water supplied directly to the filters.

The sedimentation basin is built on the river bank, largely above the natural surface of the soil. The sides are embankments made of clay obtained in excavating for the filters, mixed with gravel dredged from the river. These materials were put down in alternate 3-inch layers, wetted, and harrowed, and were rolled with 3-ton grooved rollers on the top of each gravel layer until the gravel was forced down into and thoroughly embedded in the clay. The embankments

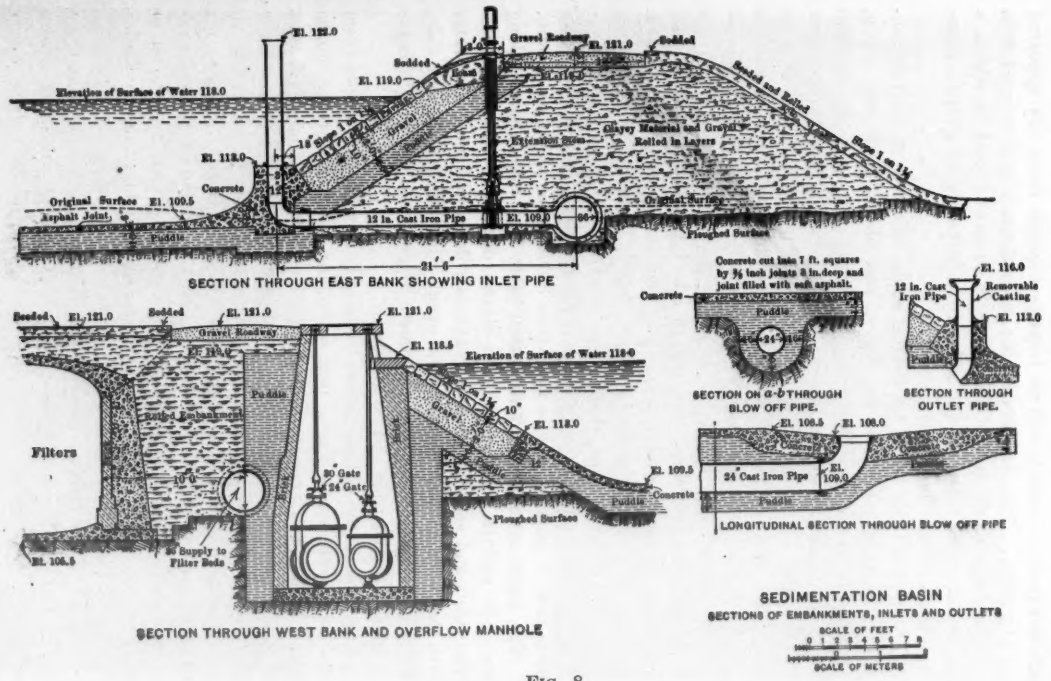

El. 122.0
Gravel Roadway
El. 121.0
Sodded
Sodded
El. 119.0
Elevation of Surface of Water 118.0
Gravel
Gravel
Earth
Gravel and Broken Stone
Elevation Stone
Gravel Material and Gravel Rolled in Layers
Rolled and Rolled
Slope 1 on 1½
El. 113.0
Concrete
Original Surface El. 109.5
Asphalt Joint
Puddle
12 in. Cast Iron Pipe
El. 109.0
Original Surface
Ploughed Surface
21′-6″
SECTION THROUGH EAST BANK SHOWING INLET PIPE
Concrete cut into 7 ft. squares by ¾ inch joints 3 in. deep and joint filled with soft asphalt.
Concrete
Puddle
24″
SECTION ON a–b THROUGH BLOW OFF PIPE.
El. 116.0
12 in. Cast Iron Pipe
Removable Casting
El. 113.0
Puddle
SECTION THROUGH OUTLET PIPE.
Seeded
El. 121.0
Sodded
El. 121.0
Gravel Roadway
El. 121.0
El. 118.5
Elevation of Surface of Water 118.0
Earth Embankment
Puddle
Gravel
10″
El. 113.0
Filters
10′-0″
30″ Gate
24″ Gate
El. 109.5
Concrete
Puddle
Ploughed Surface
El. 105.5
30″ Supply to Filter Beds
SECTION THROUGH WEST BANK AND OVERFLOW MANHOLE
El. 106.5
El. 106.0
24″ Cast Iron Pipe
El. 106.0
Puddle
LONGITUDINAL SECTION THROUGH BLOW OFF PIPE
SEDIMENTATION BASIN
SECTIONS OF EMBANKMENTS, INLETS AND OUTLETS
SCALE OF FEET
0 1 2 3 4 5 6 7 8
0 1
SCALE OF METERS

FIG. 8.

made in this way are extremely solid, stand vertically when cut, are not readily washed, and no leakage through them has appeared at any point. The outsides of the embankments are covered with soil, and the inside and bottom with 16 inches of puddle, which is protected from frost on the sides by a covering of gravel, above which is a rough blue-stone pavement.

The puddle was made by mixing equal volumes of the clay obtained in excavating for the filters, and mixed sand and gravel obtained from the river by dredging. It differed from the material of the embankments only in more thorough mixing, and greater care in placing. The materials were mixed in a pug mill. It was soon found that the best mixing was secured with rather large quantities of water, while the best ramming required that the materials should not be too wet. Accordingly, the materials were mixed wet, given a preliminary ramming, allowing to stand two or three days, and afterwards given the final ramming. The puddle was put down in three layers, and the concrete rested directly upon it. The concrete was put down in blocks about 7 feet square, with $\frac{1}{2}$-inch joints, extending halfway from top to bottom, filled with asphalt. The maximum rate of placing puddle was about 3 000 cubic yards per month.

The water enters the sedimentation basin from eleven inlets along one side and is withdrawn from eleven outlets directly opposite. The inlets and aerating devices previously described bring the water into the basin without current, and evenly distributed along one side. Both inlets and outlets are controlled by gates, so that any irregularities in distribution can be avoided.

The floor of the sedimentation basin is built with even slopes from the toe of each embankment to a sump, the heights of these slopes being 1 foot, whatever their lengths. The sump is connected with a 24-inch pipe leading to a large manhole in which there is a gate through which water can be drawn to empty the basin. There is an overflow from the basin to this manhole, which makes it impossible to fill the basin above the intended level. A section of the embankment about the sedimentation basin and other details are shown in Fig. 8. A view of a portion of the finished basin in use is shown in Fig. 1, Plate IV.

Filters. — The filters are contained in masonry chambers and are covered to protect them against the winters, which are quite severe in Albany. The piers, cross-walls, and linings of the outside walls, entrances, etc., are of vitrified brick. All other masonry is con-

FIG. 1. — PLACING THE FLOOR OF A FILTER.

FIG. 2. — BUILDING THE BRICK PIERS.

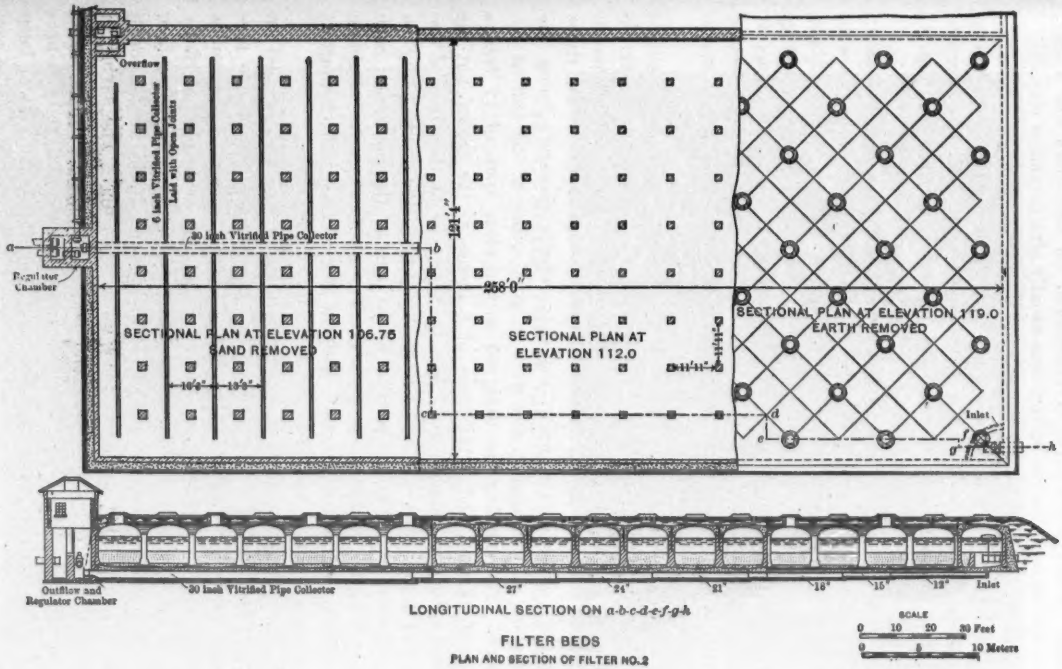

Overflow
6 Inch Vitrified Pipe Collector Laid with Open Joints
30 Inch Vitrified Pipe Collector
Regulator Chamber
121'-1"
258'-0"
SECTIONAL PLAN AT ELEVATION 106.75 SAND REMOVED
SECTIONAL PLAN AT ELEVATION 112.0
SECTIONAL PLAN AT ELEVATION 119.0 EARTH REMOVED
Inlet
Outflow and Regulator Chamber
30 Inch Vitrified Pipe Collector
27"
24"
21"
18"
15"
12"
Inlet
LONGITUDINAL SECTION ON a-b-c-d-e-f-g-h
SCALE
0 10 20 30 Feet
0 5 10 Meters
FILTER BEDS
PLAN AND SECTION OF FILTER NO. 2

FIG. 9.

crete. The average depth of excavation for the filters was 4 feet, and the material at the bottom was usually blue or yellow clay.

Floors. — The floors consist of inverted, groined, concrete arches, arranged to distribute the weight of the walls and vaulting over the whole area of the bottom. They were put in in alternate squares running diagonally with the pier lines, as shown in Fig. 1, Plate I.

Walls. — For the outside walls the brick linings, 8 inches thick, were built first to the full height. A certain number of bricks were laid endwise, and projected into the concrete. These occupied about 4% of the area of the wall. Afterwards, wooden forms were put up on the outside, and the concrete backing was filled in. Sections of the walls are shown in Fig. 10. The arrangement of the projecting brick is shown in Fig. 2, Plate II, which also shows the outside forms for the concrete wall in the distance.

Vaulting. — The concrete vaulting was placed on wooden centers supported on wedges which could be knocked out after the concrete had set, so that the centers came down readily, and could be moved forward and used again. Some of them were used four or five times in the course of the work, the only repairs necessary being the patching of the lagging, and were in good order at the end of the work. The vaulting was designed with a clear span of 12 feet, a rise of 2½ feet, and a thickness of 6 inches at the crown, but the clear span was reduced to 11 feet 11 inches to fit the sizes of the bricks in the piers. It was put in in squares, the joints being on the crowns of the arches parallel to the lines of the piers, and each pier being the center of one square. The manholes are in alternate sections, and are of concrete, built in steel forms with castings at the tops, securely jointed to the concrete.

Above the vaulting there are 2 feet of earth and soil, grassed on top. The tops of the manholes are 6 inches above the soil to prevent rain water from entering them. The drainage of the soil is effected by a depression of the vaulting over each pier, partially filled with gravel and sand, from which water is removed by a 2-inch tile drain going down the center of the pier and discharging through its side just above the top of the sand in the filter. The saving in cost by this arrangement was considerable, as the cost of the drains was much less than that of the concrete which would have been necessary to fill the areas over the piers had any other system been adopted. Further, the water entering in this way is as good as any

FIG. 1. — GENERAL VIEW OF VAULTING, UNDER CONSTRUCTION.

FIG. 2. — OUTSIDE WALL, READY FOR CONCRETE BACKING.

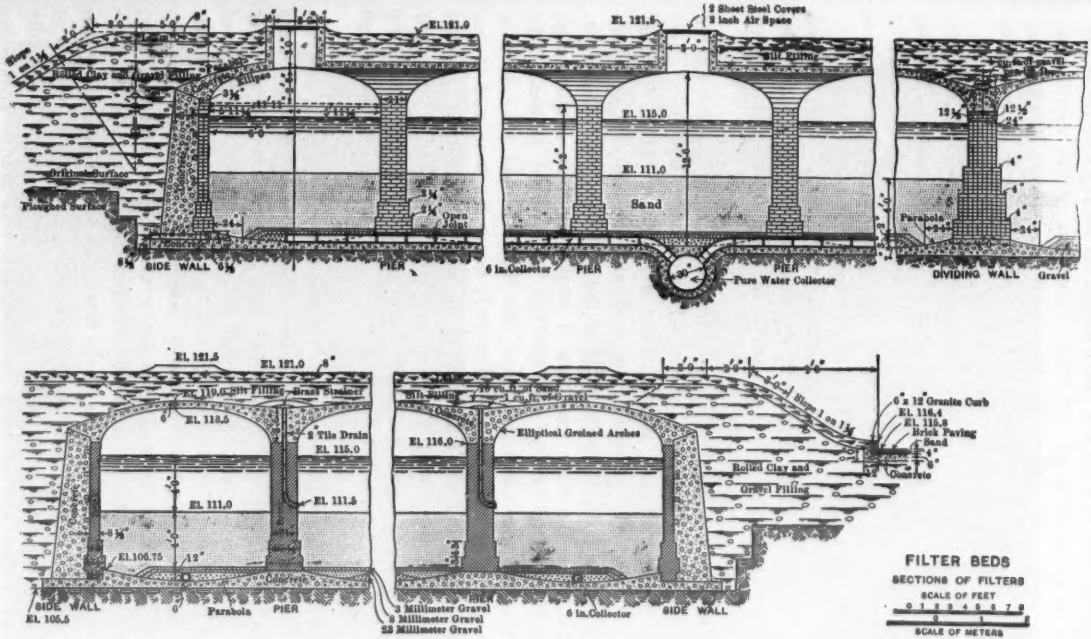

El. 121.5
El. 121.0
Slope 1 on 1¼
Rolled Clay and Gravel Filling
Puddle
Ellipse
Orikum Surface
Flooded Surface
3¼"
2¼"
Open Joint
24"
SIDE WALL
PIER
2 Sheet Steel Covers
2 inch Air Space
Silt Filling
El. 115.0
El. 111.0
Sand
6 in. Collector
Pure Water Collector
12½"
Parabola
DIVIDING WALL
Gravel
El. 118.5
Gravel Stratum
2 Tile Drain
El. 106.75
12"
El. 105.5
3 Millimeter Gravel
8 Millimeter Gravel
25 Millimeter Gravel
Elliptical Groined Arches
El. 116.0
Rolled Clay and Gravel Filling
6" x 12" Granite Curb
El. 116.4
El. 115.8
Brick Paving
Sand
Concrete
FILTER BEDS
SECTIONS OF FILTERS
SCALE OF FEET
SCALE OF METERS

FIG. 10.

water available, and there is every reason for adding it to the supply before it passes through the filters. Sections of the vaulting are shown in Fig. 10. Plate II, Fig. 1 gives a general view of the vaulting at various stages. The finished vaulting is shown from beneath in Plate III, Figs. 1 and 2.

In order to provide ready access to each filter, a part of the vaulting near one side is elevated and made cylindrical in shape, making an inclined runway from the sand level to a door, the threshold of which is 6 inches above the level of the overflow. This sand-run is provided with permanent timber runways and with secure doors.

The vaulting is similar, in many respects, to that of the covered filters at Ashland, Wis., and at Somersworth, N. H., but differs from that vaulting in that it is entirely of concrete, instead of brick backed by concrete.

Underdrains. — The main underdrains for removing the filtered water are of vitrified pipe surrounded by concrete, and are entirely below the floors of the filters. They were put in before the construction of the filters was commenced, and the concrete surrounding them was brought to the plane of the bottom of the foundations, so that when the floor was built it went over them continuously, without breaking in any way the line of inverted arches. This arrangement was adopted because the drains would have been in the way if they had been placed entirely above the floor, and if any part of the drain had been placed in the normal floor-span it would have reduced the strength of the inverted arches, and would itself have been liable to breakage by their pressure. As the surrounding material is clay or tight rock, no danger of loss of water by seepage can result from this arrangement.

The main collectors are 30-inch vitrified pipes, reduced by castings to 20 inches at the outlets, and the effluent from each filter passes through a 20-inch gate. The underdrains are made much larger than would ordinarily be required for carrying the quantities of water involved. The reason for this is that after a filter has just been scraped, the frictional loss in passing the sand is very slight. If the friction of the underdrainage system is not kept very low, there will be so much loss of head that when a filter is started the pull exerted at remote parts of the filter will be less than at points near the outlet, and thus the parts near the outlet will operate at rates which are too high, while the more remote parts will hardly filter at all, and the resulting purification is less than it should be.

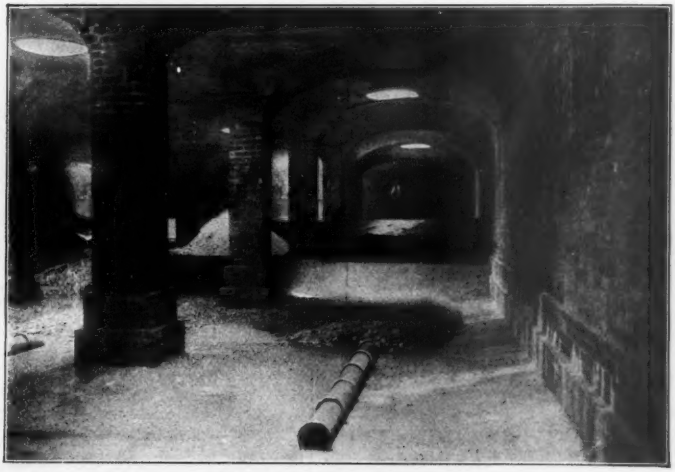


FIG. 1. — INTERIOR OF A FILTER: DRAIN, GRAVEL AND SAND LAYERS.

FIG. 2. — INTERIOR OF A FILTER, READY FOR USE.

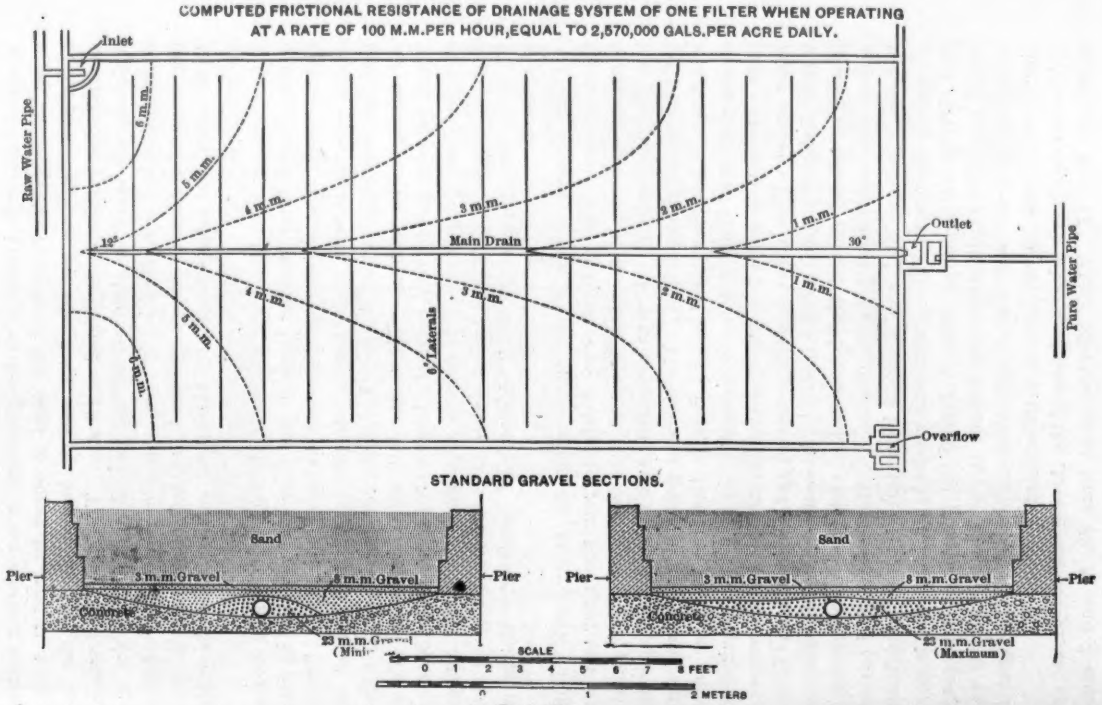

COMPUTED FRICTIONAL RESISTANCE OF DRAINAGE SYSTEM OF ONE FILTER WHEN OPERATING AT A RATE OF 100 M.M. PER HOUR, EQUAL TO 2,570,000 GALS. PER ACRE DAILY.
Inlet
Raw Water Pipe
6 m.m.
5 m.m.
4 m.m.
3 m.m.
2 m.m.
1 m.m.
12"
Main Drain
30"
Outlet
Pure Water Pipe
6" Laterals
Overflow
STANDARD GRAVEL SECTIONS.
Sand
Pier
3 m.m. Gravel
8 m.m. Gravel
Concrete
23 m.m. Gravel (Maximum)
SCALE
0 1 2 3 4 5 6 7 8 FEET
0 1 2 METERS

FIG. 11.

The underdrainage system is so designed that, when starting a filter after cleaning, the friction of the sand is about 50 mm. at a rate of 3 000 000 gallons per acre daily, and the loss of head in the underdrainage system is estimated at 10 mm. This very low friction, which is necessary, is obtained by the use of ample sizes for the underdrains and low velocities in them. In the outlet and measuring devices moderate losses of head are not objectionable, and these pipes and connections are, therefore, smaller than the main underdrains.

Connections with the drain are made through thirty-eight 6-inch outlets in each filter, passing through the floor and connecting with 6-inch lateral drains running the whole width of the filter. These drains were made with pipes having one side of the bell cut off, so that they would lie flat on the floor and make concentric joints, without having to be wedged. They were laid with a space of about 1 inch between the barrels, leaving a large opening for the admission of water from the gravel. The general arrangement of the drainage system is shown in Fig. 5. Other details are shown in Figs. 9 and 10, while the computed frictional resistance of one filter is shown in Fig. 11.

Filter Gravel. — The gravel surrounding the underdrains is of three grades. The material was obtained from the river-bed by dredging, and was of the same stock as that used for preparing ballast for the concrete. It was separated and cleaned by a special, cylindrical, revolving screen. The coarsest grade of gravel was that which would not pass round holes 1 inch in diameter, and free from stones more than about 2 inches in diameter. At first it was required to pass a screen with holes 2 inches in diameter, but this screen removed many stones which it was desired to retain, and the screen was afterwards changed to have holes 3 inches in diameter. The intermediate grades of gravel passed the 1-inch holes, and were retained by a screen with round holes $\frac{3}{8}$ inch in diameter. The finest gravel passed the above screens and was retained by a screen with round holes $\frac{3}{16}$ inch in diameter. The gravel was washed, until free from sand and dirt, by water played upon it during the process of screening, and it was afterwards taken over screens in the chutes where it was separated from the dirty water, and, when necessary, further quantities of water were played upon it at these points.

The average mechanical analyses of the three grades of gravel are shown by Fig. 13. Their effective sizes were 23, 8, and 3 mm.,

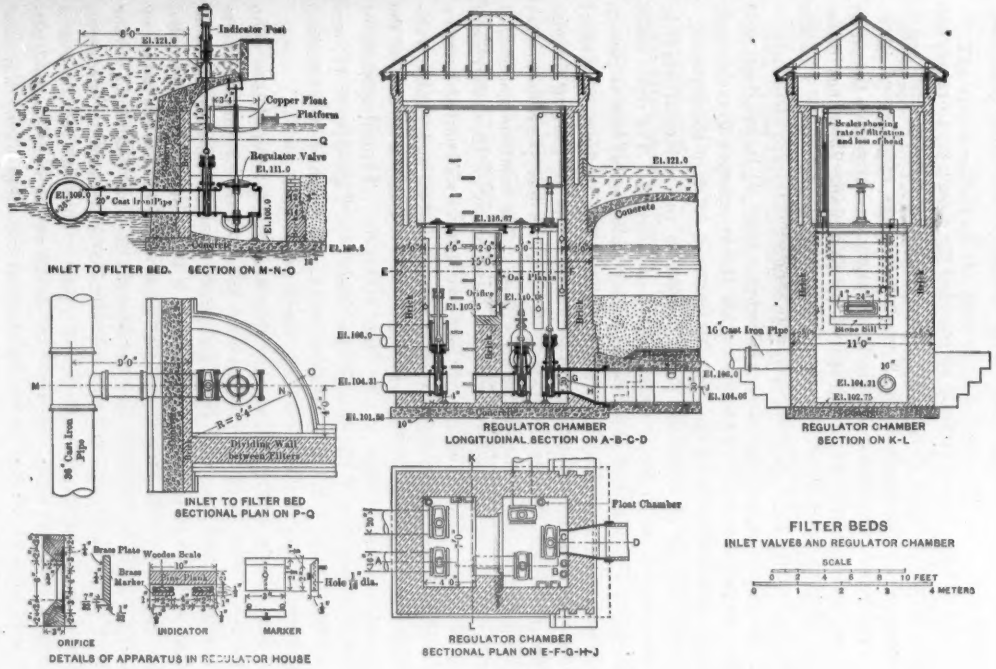

Indicator Post
Copper Float
Platform
Regulator Valve
El. 111.0
20" Cast Iron Pipe
INLET TO FILTER BED. SECTION ON M-N-O
Dividing Wall between Filters
INLET TO FILTER BED
SECTIONAL PLAN ON P-Q
Brass Plate
Wooden Scale
Brass Marker
Hole 1/4 dia.
ORIFICE
INDICATOR
MARKER
DETAILS OF APPARATUS IN REGULATOR HOUSE
Concrete
Oak Planks
Orifice
REGULATOR CHAMBER
LONGITUDINAL SECTION ON A-B-C-D
Float Chamber
REGULATOR CHAMBER
SECTIONAL PLAN ON E-F-G-H-J
Scales showing rate of filtration and loss of head
Stone Sill
16" Cast Iron Pipe
REGULATOR CHAMBER
SECTION ON K-L
FILTER BEDS
INLET VALVES AND REGULATOR CHAMBER
SCALE
10 FEET
4 METERS

FIG. 12.

respectively, and, for convenience, they are designated by these numbers. The average uniformity coefficient for each grade was about 1.8.

The 23-mm. gravel entirely surrounded the 6-inch pipe drains, and was carried slightly above their tops. In some cases it was used to cover nearly the whole of the floor, but this was not insisted upon.

The 8-mm. gravel was obtained in larger quantity than the other sizes, and was used to fill all spaces up to a plane 2½ inches below the finished surface of the gravel, this layer being about 2 inches thick over the tops of the drains, and somewhat thicker elsewhere.

The 3-mm. gravel was then applied in a layer 2½ inches deep, and the surface leveled. The grades for the two upper gravel layers were shown directly by the joints in the brick work of the piers.

The form of construction made it best to put a lateral drain in each section, or 13 feet 8 inches apart on centers. The drain itself occupies 7 inches, and the longest course which water has to pass in the gravel, in any event, is about 6½ feet. This distance is so short that the frictional resistance of the filtered water in passing through the gravel is extremely small, and, therefore, it was possible to vary the gravel sections somewhat according to the relative amounts of gravel of the several grades obtained in screening, without detriment to the work. The thickness of the 3-mm. gravel was varied between 2 and 2½ inches, according to the supply available, and similar variations were made in the other grades; but the finished surface of the gravel was always kept at the same elevation. Typical sections of the arrangements of the gravels are shown in Figs. 10 and 11, and in Fig. 1, Plate III. The greatest rate at which gravel was obtained and placed was about 1 500 cubic yards per month.

Filter Sand. — The preliminary estimates of cost were based upon the use of filter sand from a bank near the filter site. Further examination showed that this sand contained a considerable quantity of lime, and it was found by experiment with a small filter constructed for that purpose that the use of this sand would harden the water by about 2 parts in 100 000, and the amount of lime contained in the sand, namely, about 7%, was sufficient to continue this hardening action for a considerable number of years. This was regarded as a serious objection to its use, and the specifications were drawn limiting the amount of lime in the sand, thus excluding all of the local bank sands. The river sands which were used were nearly free from lime, and in the end the sand as secured was probably not only free

from lime, but more satisfactory in other ways, and also cheaper than the bank sand would have been.

The specifications of the filter sand require that —

"The filter sand shall be clean river, beach or bank sand, with either sharp or rounded grains. It shall be entirely free from clay, dust or organic impurities, and shall, if necessary, be washed to remove such materials from it. The grains shall, all of them, be of hard material, which will not disintegrate, and shall be of the following diameters: Not more than 1% by weight less than 0.13 mm., nor more than 10% less than 0.27 mm.; at least 10% by weight shall be less than 0.36 mm. and at least 70%, by weight, shall be less than 1 mm., and no particles shall be more than 5 mm. in diameter. The diameters of the sand grains will be computed as the diameters of spheres of equal volume. The sand shall not contain more than 2%, by weight, of lime and magnesia taken together and calculated as carbonates."

With the river sand and the method of handling adopted by the contractors, it was possible to control the quality of the sand, so that the specifications were complied with. In the lower layers of two of the filters a little sand was allowed which contained a few particles above 5 mm. in diameter. The screens were adjusted afterwards so that the largest remaining particles were less than 4 mm. in diameter. The filter sand has effective sizes of from 0.29 to 0.32 mm., averaging 0.31; and uniformity coefficients from 2.2 to 2.5, averaging 2.3. Its mechanical composition is shown by the diagram, Fig. 13.

The sand and also the gravel were delivered in the filters through the manholes, temporary plank roadways being built for that purpose. Trucks carrying 1½ cubic yards, with a pair of horses, were driven over the vaulting in all directions, without hesitation and without damage to it. The sand was dumped on plank platforms constructed below. A record was kept of all the planks used for this purpose, and they were required to be taken up in the presence of inspectors afterwards to prevent the possibility of leaving any of them in the filter. This arrangement necessitated working over all the sand underneath the points of dumping, and it thereby became loosened from the excessive packing caused by dumping it from a height. The sand was deposited in three horizontal layers, so that, if by accident sand of unusual quality was placed at any point, the same kind of sand would not extend from top to bottom. The method of placing the sand in layers is shown in Fig. 1, Plate III,

which also shows the gravel layers and a lateral underdrain; while a completed filter with the sand smoothed ready for use is shown in Fig. 2, Plate III.

Sand-washing Apparatus. — Most of the suspended matters in the filtered water are held by the top layer of sand, and this layer is removed from time to time. The dirty sand is washed, and eventually replaced in the filters. Two ejector sand-washing machines, shown in Fig. 14, are provided at convenient places between the filters. In them the dirty sand is mixed with water, and is thrown up by an ejector, after which it runs through a chute into a receptacle, from which it is again lifted by another ejector. It passes in all through five ejectors, part of the dirty water being wasted each time. The sand is finally collected from the last ejector, where it is allowed to deposit from the water.

Sand washers of this kind have been used for many years by some of the London water companies, and more recently at Hamburg; and also at Lawrence and Poughkeepsie in this country.

The entire central court between the filters and about the sand washers, shown in Fig. 2, Plate IV, is paved with brick upon a concrete foundation, and affords a convenient space for handling and storing sand.

Inlets to Filters. — Water is admitted to each filter through a 20-inch pipe from a pipe system connecting with the sedimentation basin. Just inside of the filter wall is placed a standard gate and beyond that a balanced valve connected with an adjustable float to shut off the water when it reaches the desired height on the filter (Fig. 12). These valves and floats were constructed from special designs, and are similar in principle to valves used for the same purpose in the Berlin water filters.

Overflows. — Each filter is provided with an overflow, so arranged that it cannot be closed, which prevents the water level from exceeding a fixed limit in case the balanced valve fails to act. An outlet is also provided near the sand-run, so that unfiltered water can be removed quickly from the surface of the filter, should it be necessary, to facilitate cleaning.

Filter Outlets. — The outlet of each filter is through a 20-inch gate controlled by a standard graduated to show the exact distance the gate is open. The water rises in a chamber and flows through an orifice in a brass plate 4 by 24 inches, the center of which is 1 foot below the level of the sand line. At the normal rate of filtration,

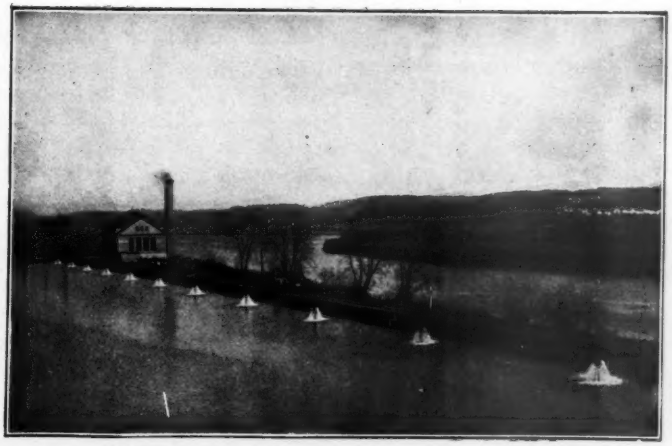


FIG. 1. — SEDIMENTATION BASIN, PUMPING STATION, AND OUTLETS.

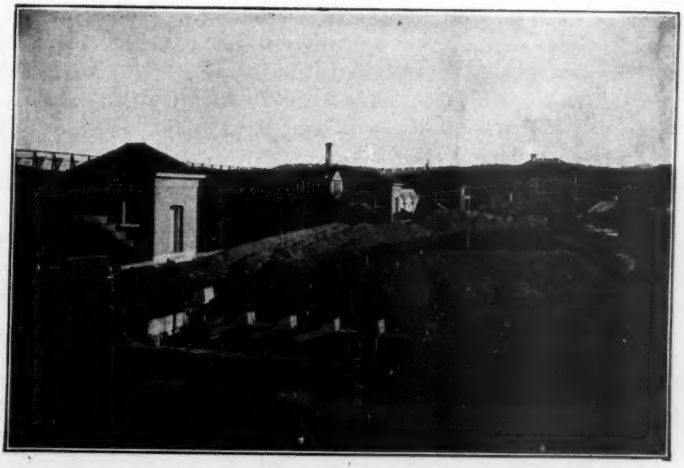


FIG. 2. — CENTRAL COURT, SHOWING SAND WASHER, DIRTY SAND, ETC.

3 000 000 gallons per acre daily, 1 foot of head is required to force the water through the orifice. With other rates the head increases or decreases approximately as the square of the rate and forms a measure of it. With water standing in the lower chamber, so that the orifice is submerged, it is assumed that the same rate will be obtained with a given difference in level between the water on the two sides of the orifice, as from an equal head above the center of the orifice when discharging into air. The general arrangement of the gate-houses, including the gates for wasting the effluent to the river, for filling filters with filtered water from below, etc., is shown in Fig. 12, while outside views of gate-houses are shown in Fig. 2, Plate I, and Fig. 2, Plate IV.

Measurement of Effluent. — In order to show the rate of filtration two floats are connected with the water on the two sides of the orifice. These floats are counterbalanced; one carries a graduated scale and the other a marker which moves in front of the scale and shows the rate of filtration corresponding to the difference in level of the water on the two sides.

When the water in the lower chamber falls below the center of the orifice, the water in the float chamber is, nevertheless, maintained at this level. This is accomplished by making the lower part of the tube water-tight, with openings just at the desired level, so that when the water falls below this point in the outer chamber it does not fall in the float chamber. To prevent the loss of water in the float chamber by evaporation, or from other causes, a lead pipe is brought from the other chamber and supplies a driblet of water to it constantly; this overflows through the openings, and maintains the water level at precisely the desired point. The floats thus indicate the difference in water level on the two sides of the orifice whenever the water in the lower chamber is above the center of the orifice; otherwise, they indicate the height of water in the upper chamber above the center of the orifice, regardless of the water level in the lower chamber. The scale is graduated to show the rates of filtration in millions of gallons per acre of filtering area. In computing this scale the area of the filters is taken as 0.7 acre, and the coefficient of discharge as 0.61.

At the ordinary rates of filtration the errors introduced by the different conditions under which the orifice operates will rarely amount to as much as 100 000 gallons per acre daily, or one thirtieth of the ordinary rate of filtration. Usually they are much less than

this. The apparatus thus shows directly, and with substantial accuracy, the rate of filtration under all conditions.

Measurement of Loss of Head. — Two other floats with similar connections show the difference in level between the water standing on the filter and the water in the main drain pipe back of the gate, or in other words, the frictional resistance of the filter, including the drains. This is commonly called the loss of head, and increases from 0.2 foot or less, with a perfectly clean filter, to 4 feet, with the filter ready for cleaning. When the loss of head exceeds 4 feet the rate of filtration cannot be maintained at 3 000 000 gallons per acre daily with the outlet devices provided, and, in order to maintain the rate, the filter must be cleaned.

The outlets of the filters are connected in pairs, so that filtered water can be used for filling the underdrains and sand of the filters from below prior to starting, thus avoiding the disturbance which results from bringing dirty water upon the sand of a filter not filled with water.

Laboratory Building.—The scientific control of the filters is regarded as one of the essentials to the best results, and to provide for this there is a laboratory building at one end of the central court between the filters and close to the sedimentation basin, supplied with the necessary equipment for full bacterial examinations, and also with facilities for observing the colors and turbidities of raw and filtered waters, and for making such chemical examinations as may be necessary. This building also provides a comfortable office, dark room and storage room for tools, etc., used in the work.

Pure-water Reservoir. — A small pure-water reservoir, 94 feet square, and holding about 600 000 gallons, is provided at the filter plant. The construction is similar to that of the filters, but the shapes of the piers and vaulting were changed slightly, as there was no necessity for the ledges about the bottoms of the piers and walls; while provision is made for taking the rain water, falling upon the vaulting above, to the nearest filters instead of allowing it to enter the reservoir. The floor and roof of the reservoir are at the same levels as those of the filters.

Pure-water Conduit. — The filtered water is taken from the pure-water reservoir to the present pumping station through 7 913 feet of 48-inch pipe. For 5 450 feet the pipe is laid under the Erie Canal, and for 1 837 feet through Montgomery Street, with an average cut of 22 feet. The pipe is not under pressure, and is made of mild open-hearth steel plates, $\frac{5}{16}$ inch thick.

Concrete Backing. — Pipe of this thickness is not stiff enough to withstand the earth pressures in the deep cut in Montgomery Street, without being badly deformed, and is not heavy enough to be safe from the danger of floating in the canal, should the water be removed from the pipe for any reason. Concrete was therefore used to support the sides of the pipe in the deep cut and to weight it under the canal. The amount of concrete required for these purposes was considerable, and the Board decided to use a further amount in order to surround the pipe entirely. This makes a concrete pipe with a minimum thickness of 6 inches outside of the steel pipe for practically the whole distance, capable of supporting the earth, and able itself to serve as a conduit even if the steel pipe should be removed entirely, although in that case it would not be thoroughly water-tight. For 567 feet on hard clay bottom, the concrete on the bottom was omitted, the natural material being probably equivalent to the concrete. For about 300 feet at the upper end, in shallow cut and where the pipe is readily accessible, the concrete was also omitted.

Coating. — The pipe was coated by dipping in asphalt, and after calking tight on the inside, all imperfections in the coating, due to calking or otherwise, were covered with melted asphalt in connection with a naphtha lamp. Where the spots were not too large the asphalt on the sides came together when softened by the flame and covered the spot completely without the addition of new material. Where the uncovered patches were large this was not possible. The place was first heated, then melted asphalt was applied and thoroughly heated and melted until it incorporated itself with the old asphalt on the edges.

The greatest difficulty was experienced in repairing breaks in the coating directly on the bottom of the pipe; although these were not serious, owing to the fact that all men who worked therein were required to wear rubbers, and thus the damage done to the coating was slight. Repairs were made by building dams of cotton waste on each side of the defective place and sponging out the water, after which the plates could be heated by a naphtha lamp and repaired in the usual way.

Brick Work. — All the brick work, except that in the superstructures, was of vitrified paving brick. This brick was not specified, but the specifications required brick absorbing not more than 12% of water by weight. The local brick-makers were unwilling to take the

trouble to make brick hard enough to meet this requirement, and the contractors decided finally to use a second-quality paving brick. With this, the absorption ranged from 1 to 11%, and averaged 4% by weight.

Cracks. — With cold weather, some of the joints in the concrete vaulting opened slightly, indicating the absence of arch action, but no cracks in the blocks have been observed at any point. A few cracks appeared in the walls, none of which was of serious consequence.

CAPACITY OF PLANT AND MEANS OF REGULATION.

The various filters have effective filtering areas of from 0.702 to 0.704 acre, depending upon slight differences in the thickness of the walls in different places. For the purpose of computation, the area of each filter is taken at 0.7 acre. The normal rate of filtration is taken as 3 000 000 gallons per acre daily, at which rate each filter will yield 2 100 000 gallons daily, and, with one filter out of use for the purpose of being cleaned, seven filters normally in use will yield 14 700 000 gallons. The entrances and outlets are all made of sufficient size, so that rates 50% greater than the foregoing are possible. The capacities of the intake, pumping station, and piping are such as to supply any quantity of water which the filters can take, up to an extreme maximum of 25 000 000 gallons in 24 hours. The pure-water conduit from the filters to Quackenbush Street is nominally rated at 25 000 000 gallons per 24 hours, after it has become old and somewhat tuberculated. In its present excellent condition it will carry a larger quantity.

At the pumping station at Quackenbush Street there are three Allis pumps, each capable of lifting 5 000 000 gallons per 24 hours. In addition to the above there are the old reserve pumps with a nominal capacity of 10 000 000 gallons per 24 hours, which can be used if necessary, but which require so much coal that they are seldom used. For practical purposes the 15 000 000 gallons represents the pumping capacity of this station and also the capacity of the filters, but the arrangements are such that in case of emergency the supply can be increased to 20 000 000 or even 25 000 000 gallons for a short time.

The water is pumped through rising mains to reservoirs holding 37 000 000 gallons, not including the Tivoli low-service reservoir, which is usually supplied from gravity sources. The reservoir capacity is such that the pumping can be suspended at Quackenbush Street for considerable periods if necessary, and in practice it has

been suspended at certain times, especially on Sundays. The amount of water required is also somewhat irregular. The drainage areas supplying the gravity reservoirs are much larger, relatively, than the reservoirs, and at flood periods the volume of the gravity supply is much greater than that which can be drawn in dry weather. Thus it happens that, at certain seasons of the year, the amount of water to be pumped is but a fraction of the nominal capacity of the pumps, and at these times it is possible to shut the pumps down for greater lengths of time.

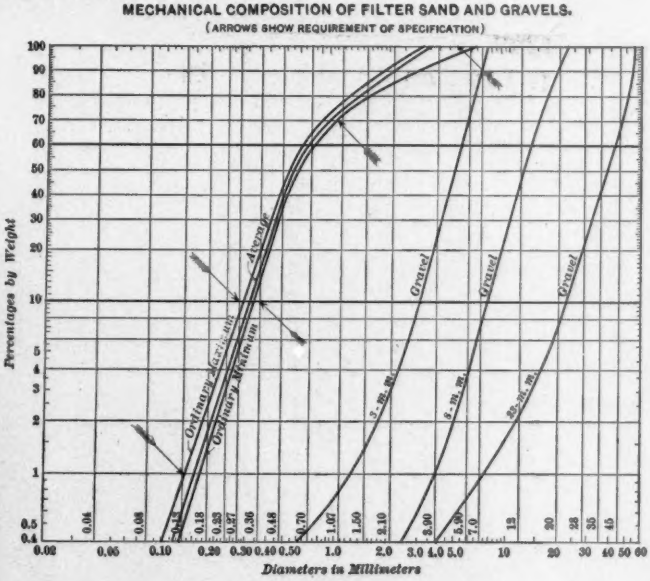


FIG. 13.

Capacity of Pure-water Reservoir. — The storage capacity provided between the filters and the Quackenbush Street pumps is comparatively small, namely, 600 000 gallons, or one hour's supply at the full nominal rate. A larger basin, holding as much as one third or one half of a day's supply, would be in many respects desirable in this position, but the conditions were such as to make it practically impossible. The bottom of the reservoir could not be put lower without deepening and increasing greatly the expense of the conduit line. On the other hand, the flow line of the reservoir could not be

raised without raising the level of the filters, which was hardly possible upon the site selected. The available depth was thus limited between very narrow bounds, and to secure a large capacity would have necessitated a very large area, and consequently a great expense. Under these circumstances, and especially in view of the abundant storage capacity for filtered water in the distributing reservoirs, it was not deemed necessary to secure a large storage, and only so much was provided as would allow the pumps to be started at the convenience of the engineer, and give a reasonable length of time for the filters to be brought into operation. For this the pure-water reservoir is ample, but it is not enough to balance any continued fluctuations in the rate of pumping.

Method of Regulating and Changing the Rate of Filtration. — With all the Allis pumps running at their nominal capacity, the quantity of water required will just about equal the normal capacity of the filters. When only one or two pumps are running, the rate of filtration can be reduced. With the plant operating up to its full capacity, the water level in the pure-water reservoir will be below the level of the standard orifices in the filter outlets. When the rate of pumping is reduced, if no change is made in the gates controlling the filter outlets, the water will gradually rise in the pure-water reservoir and in the various regulator chambers, and will submerge the orifices and gradually reduce the head on the filters, and consequently the rates of filtration, until those rates equal the quantity pumped. In case the pumping is stopped altogether, the filters will keep on delivering at gradually reduced rates until the water level in the pure-water reservoir reaches that of the water on the filters.

When the pumps are started up, after such stoppage or reduced rate of pumping, the water levels in the pure-water reservoir and in the gate chambers will be lowered gradually, and the filters will start to operate at first with extremely low rates which will increase gradually until the water is depressed below the orifices, when they will again reach the rates at which they were last set. The regulators during all this time will show the rate of filtration on each filter, and, if any inequalities occur which demand correction, the gates on the various outlets can be adjusted accordingly.

The arrangement, in this respect, combines some of the features of the English and German plants. In the English plants the filters are usually connected directly with the clear-water basin, and that in turn with the pumps, and the speed of filtration is required to respond

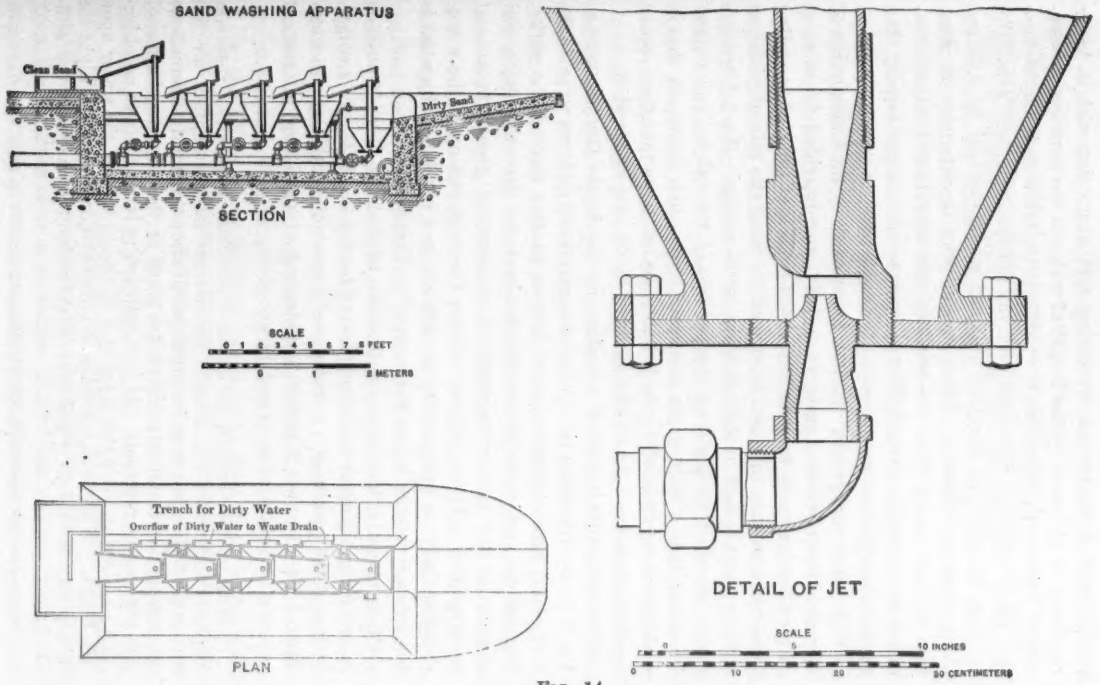

SAND WASHING APPARATUS
Clean Sand
Dirty Sand
SECTION
SCALE
0 1 2 3 4 5 6 7 8 FEET
0 1 2 METERS
Trench for Dirty Water
Overflow of Dirty Water to Waste Drain
PLAN
DETAIL OF JET
SCALE
0 5 10 INCHES
0 10 20 30 CENTIMETERS

FIG. 14.

to the speed of the pumps, increasing and decreasing with it, being regulated at all times by the height of water in the pure-water reservoir. This arrangement has been subject to severe criticism, because the rate of filtration fluctuates with the consumption, and especially because the rates of filtration obtained simultaneously in different filters may be different. There was no way to determine at what rate any individual filter was working, and there was always a tendency for a freshly scraped filter to operate much more rapidly than those which had not been scraped for some time.

This led to the procedure, first formulated by the Commission of German Water Works Engineers in 1894, and provided for in most of the German works built or remodeled since that time, of providing pure-water storage sufficient in amount to make the rate of filtration entirely independent of the operation of the pumps. Each filter was to be controlled by itself, be independent of the others, and deliver its water into a pure-water reservoir lower than itself, so that it could never be affected by back-water, and so large that there would never be a demand for sudden changes in the rate of filtration.

This procedure has given excellent results in the German works; but it leads oftentimes to expensive construction. It involves, in the first place, a much greater loss of head in passing through the works, because the pure-water reservoir must be lower than the filters, and the cost of the pure-water reservoir is increased greatly because of its large size. The regulation of the filters is put upon the attendants entirely, or upon automatic devices, and regulation by what is known as "responding to the pumps" is eliminated.

More recently the German authorities have shown less disposition to insist rigidly upon the principles advanced in 1894. In a compilation of the results of several years' experience with German water filters, Dr. Pannwiz * makes a statement of particular interest, of which a free translation is as follows: —

"Most of the German works have sufficient pure-water reservoir capacity to balance the normal fluctuations in consumption, so that the rate of filtration is at least independent of the hourly fluctuations in consumption. Of especial importance is the superficial area of the pure-water reservoir. If it is sufficiently large there is no objection to allowing the water level in it to rise to that of the water upon the filters. With very low rates of consumption during the night the filters may work slowly and even stop, without damage to the sedi-

* *Arbeiten aus dem Kaiserlichen Gesundheitsampte*, Vol. XIV, p. 260.

ment layers when the stopping and starting take place slowly and regularly, because of the ample reservoir area.

"The very considerable fluctuations from day to day, especially those arising from unusual and unforeseen occurrences, are not provided for entirely by even very large and well-arranged reservoirs. To provide for these without causing shock, the rate of filtration must be changed carefully and gradually, and the first essential to success is a good regulation apparatus."

"Responding to the pumps" has a great deal to recommend it. It allows the pure-water reservoir to be put at the highest possible level, it reduces to a minimum the loss of head in the plant, and yet provides automatically, and without the slightest trouble on the part of the attendants, for the delivery of the required quantity of water by the filters at all times. If the filters are connected directly to the pumps there is a tendency for the pulsations of the pumps to disturb their operation, even if the pumps are far removed; and this exists where filters are connected directly to the pumps, and a pure-water reservoir is attached to them indirectly. By taking all the water through the pure-water reservoir and having no connection except through it, this condition is absolutely avoided, and the pull on the filters is at all times perfectly steady.

Much has been said as to the effect of variation in the rate of filtration upon the efficiency of filters. Experiments have been made at Lawrence and elsewhere which have shown that, as long as the maximum rate does not exceed a proper one, and under reasonable regulations, and with the filter in all respects in good order, no marked decrease in efficiency results from moderate fluctuations in rate. There is probably a greater decrease of efficiency by stopping the filter altogether, especially if it is done suddenly, than by simply reducing the rate. The former sometimes results in loosening air bubbles in the sand, which rise to the surface and cause disturbances, but this is not often caused by simple change in rate.

On the whole, there is little evidence to show that, within reasonable limits, fluctuations in rate are objectionable, or should be excluded entirely, especially in such cases as at Albany, where arrangements to prevent them would have resulted in very greatly increased first cost. The inferior results sometimes obtained with the system of "responding to the pumps" as it existed in earlier works, and still exists in many important places, undoubtedly arises from the fact that there is no means of knowing and controlling the simultaneous rate of filtration in different filters, and that one filter

may be filtering two or three times as fast as another, with nothing to indicate it.

This contingency is fully provided for in the Albany plant. The orifices are of such size that even with a filter just scraped and put in service, with the minimum loss of head, with the outlet gate wide open, and with the water level in the pure-water reservoir clear down, — that is, with the most unfavorable conditions which could possibly exist, the rate of filtration cannot exceed 5 000 000 or 6 000 000 gallons per acre daily, or double the nominal rate. This rate, while much too high for a filter which has just been cleaned, is not nearly as high as was possible, and in fact actually occurred in the old Stralau filters at Berlin, and in many English works; and, further, such a condition could only occur through the gross negligence of the attendants, because the rate of filtration is indicated clearly at all times by the gages. These regulating devices have been specially designed to show the rate with unmistakable clearness, so that no attendant, however stupid, can make an error by an incorrect computation from the gage heights. It is believed that the advantage of clearness by this procedure is much more important than any increased accuracy which might be secured by refinements in the method of computation, which should take into account variations in the value of the coefficient of discharge, but which would render direct readings impossible.

In designing the Albany plant the object has been to combine the best features of German regulation with the economical and convenient features of the older English system, and filters are allowed to respond to the pumps within certain limits, while guarding against the dangers ordinarily incident thereto.

RESULTS OF OPERATION.

The filters were designed to remove from the water the bacteria which cause disease. They have already reached a bacterial efficiency of over 99%, and it is expected that their use will result in a great reduction in the death rate from water-borne diseases in the city. They also remove a part of the color and all of the suspended matters and turbidity, so that the water is satisfactory in its physical properties.

The filters have reached, with perfect ease, their rated capacity, and on several occasions have been operated to deliver one third

more than this amount; that is to say, at a rate of 4 000 000 gallons per acre daily. They are operated by Mr. George I. Bailey, Superintendent of the Albany Water Works.

COST OF CONSTRUCTION.

The cost of the filtration plant complete is shown by Table No. 3. As some of the accounts are not yet closed, a few of the items, designated by stars (*) are estimated, and are subject to slight change with the closing of all the accounts.

The filters, sedimentation basin, and pure-water reservoir are connected in such a way as to make an exact separation of their costs impossible; but, approximately, the sedimentation basin cost $60 000, the pure-water reservoir $9 000, and the filters $255 000. The sedimentation basin thus cost $4 100 per million gallons capacity; and the filters complete, including all piping, cost $45 600 per acre of net filtering area, exclusive of land and engineering.

TABLE No. 3. — Approximate Cost of Filtration Plant Complete.

Land		$8 290.00
Pumping Station:		
Pumping machinery, boilers, etc.	$22 000.00	
Intake	3 800.00	
Pump well, gates, screens, and foundations	6 285.00	
Pumping station building	12 167.00	
Chimney	1 540.00	
Venturi meter	1 560.00	
Extra work and minor items	2 393.00*	
		49 745.00*
Filters, Sedimentation Basin, and Pure-water Reservoir: —		
Preliminary draining	$1 956.71	
70 672 cu. yds. excavation, at (average) $0.3079+	21 761.64	
16 040 cu. yds. rolled clay and gravel embankment, at $0.52	8 340.80	
22 851 cu. yds. silt and loam filling, at $0.15	3 427.65	
23 439 cu. yds. general filling rolled, at $0.18	4 219.02	
12 550 cu. yds. puddle, at $0.715	8 973.25	
1 775 cu. yds. gravel for lining, at $0.85	1 508.75	
2 257 sq. yds. split stone lining, at $0.82	1 850.74	
11 737 cu. yds. concrete in floors, at $2.31	27 112.47	
Carried forward	$79 151.03	58 035.00*

Brought forward	$79 151.03	$58 035 00*
7 792 cu. yds. concrete in vaulting, at $3.85	29 999.20	
3 147 cu. yds. all other concrete, at $2.13	6 703.11	
4 382 cu. yds. brick work, at $8.125	35 603.75	
31 715 barrels Portland cement, at $1.935	61 368.53	
7 281 cu. yds. filter gravel, at $1.05	7 645.05	
36 488 cu. yds. filter sand, at $1.00	36 488.00	
Cast-iron pipes and specials, placed, including placing gates	21 841.25	
Gates and valves	6 714.23	
Vitrified pipe, complete	7 153.32	
672 filter manhole covers, at $4.40	2 956.80	
8 sand-run fixtures, at $407.50	3 260.00	
8 regulator houses, at $862.24	6 897.92	
1 office and laboratory	4 881.00	
Vitrified brick paving	2 158.00	
Iron fence about court	1 704.00	
Extra work and all minor items	9 692.01	
		324 217.20
Conduit and Connections with Quackenbush Street Pumping Station: —		
7 913 ft. 48-in. steel pipe, at $4.50	$35 608.50	
24 218 cu. yds. excavation, at (average) $0.855+	20 715.60	
3 144 cu. yds. concrete, at $5.00	15 720.00	
Gates and connections with pumping station	3 680.00	
Sewer and railroad crossings, sheeting, and all other items	10 914.12	
		86 638.22
Engineering, inspection, printing, etc.		31 000.00*
Total approximate cost of work		$499 890.42*

The preliminary estimate of cost submitted to the Board, February 8, 1897, amounted to $478 000. The work will actually cost, in round numbers, $22 000, or 4.6% more than the preliminary estimate. The preliminary estimate, and the actual costs by more important divisions, are as follows: —

	Preliminary estimate, Feb. 8, 1897.	Approximate actual cost.
Land	$10 000	$8 290
Pumping station and intake	34 000	49 745
Filters and sedimentation basin, with piping	327 000	324 217
Pure-water conduit and connection with Quackenbush Street pumping station	64 000	86 638
Engineering and contingencies	43 000	31 000
Total	$478 000	$499 890

The excess in the cost is in the pumping station and conduit line. The cost of the conduit line was increased by surrounding it with concrete, which was not included in the preliminary estimate, and also by certain changes in the location required by the canal authorities. The pumping station also was made more elaborate and expensive than was contemplated in the preliminary estimate. Otherwise the work was executed substantially as first planned.

ACKNOWLEDGMENT.

The general plan and location of the plant were first conceived by the Superintendent of Water Works, Mr. George I. Bailey, and the successful execution is largely due to his efforts. The members of the Water Board, and especially the Construction Committee, have followed the work in detail closely and personally, and their interest and support have been essential factors in the results accomplished. In the designs and specifications for the pure-water conduit the author is greatly indebted to Mr. Emil Kuichling, and also for most valuable suggestions relative to the performance of this part of the work. To Mr. William Wheeler, of Boston, the author is indebted for advice upon the vaulting and cross-sections of the walls, and these matters were submitted to him before the plans were put in final shape. All the architectural designs have been supplied by Mr. A. W. Fuller, of Albany. Mr. W. B. Fuller, as Resident Engineer, has been in direct charge of the work, and its success is largely due to his interest in it and the close attention which he and the assistant engineers have given it.

Discussion.*

BY MR. GEORGE I. BAILEY, SUPERINTENDENT, ALBANY WATER WORKS.

OPERATION.

Two filters were put in service July 27, 1899. Four more were started July 28. All of these ran until August 9, and three of them continued until August 12. They were started with the hope of continuing, but the conditions were unfavorable in that the water was pumped direct to the filters, as the sedimentation basin was not ready for use; the court between the filters, in which scraped sand

* Abstracted by the editor from a discussion in *Proceedings American Society of Civil Engineers*, February, 1900.

was to be deposited, washed and stored, was neither leveled nor paved; and the water in the river was roiled and disturbed by the contractors' operations, and particularly with the wash-water from the sand being prepared for the remaining two filters. The run of the filters was, therefore, stopped and not again commenced until September 5, since which time their operation has been continuous.

COST OF OPERATION.

The work was organized as follows: —

Filter operation:	10 laborers,	at	$1.50 per day.
	1 foreman	,,	2.75 ,,
	1 watchman	,,	1.50 ,,
	1 chemist	,,	1 000.00 per year.
Pumping Station:	3 engineers	,,	75.00 per month.
	3 firemen	,,	60.00 ,,

The working day is eight hours for laborers, engineers, and firemen, and overtime is paid for at the rates named. Occasionally, extra help has been hired, and paid for at these rates.

The gross cost of operation, including pay roll, tools which are still in use, repairs, supplies of all kinds, wash-water, etc., for the period from September 5 to December 25, inclusive, 118 days, was $6 164.94. In this time 1 470 000 000 gallons were filtered, making an average of $4.19 per million gallons delivered from the filters.

The master mechanic of the works gives the following statement from his records, as the daily cost at the pumping station: —

3 engineers	at	$2.48	$7.44
3 firemen	,,	1.98	5.94
3 tons coal	,,	2.72	8.16
1 laborer	,,	1.50	1.50
9 gallons engine oil	,,	0.09	0.81
2 gallons cylinder oil	,,	0.11	0.22
5 gallons kerosene oil	,,	0.10	0.50
5 lbs. waste	,,	0.07	0.35
Steam packing, sheet rubber, soap, soda, mops, cloths, etc.			6.58
Total			$31.50

This makes the average cost of pumping $2.52 per million gallons received from the filters, and leaves $1.67 as the cost of operating the filters, including laboratory work. The cost of scraping, wheel-

ing out, washing and replacing sand for the actual number of hours, and exclusive of superintendence, laboratory work, lost time, tools, etc., is $1.19 per million gallons treated.

BACTERIA.

Table No. 4 shows the weekly averages of the bacterial removal.

TABLE No. 4.

1899. Week ending	Bacteria Per Cubic Centimeter.		Percentage of removal.
	Unfiltered.	Filtered.	
September 9	11 545	608	94.8
16	14 083	306	97.8
23	17 480	273	98.5
30	22 600	259	98.8
October 7	18 766	250	98.7
14	11 783	178	98.5
21	9 933	85	99.1
28	4 733	84	98.4
November 4	6 091	56	99.1
11	5 141	46	99.1
18	7 950	69	99.1
25	11 090	79	99.3
December 2	19 240	109	99.4
9	20 016	198	99.1
16	57 700	142	99.7
23	66 000	327	99.5
30	48 940	215	99.6

CLEANING THE FILTERS.

The filters have been cleaned 26 times in all, up to December 25, or a little more than three times each. The total amount of sand treated, as measured when replaced, was 850 cubic yards. From the books of the foreman, the following records are taken: —

Scraping. — 88 452 sq. yds. = 18.3 acres; time, 1 227 hours = 67 hours per acre.

Wheeling out Scraped Sand. — 23 180 barrows, 2 235 hours, 27.3 barrows per cubic yard = 0.38 cu. yd. per hour. The average length of wheel, going and coming, was 600 feet = 1.18 miles per man per hour.

Washing. — 18 262 barrows, 2 068 hours, 21.5 barrows per cubic yard = 0.41 cu. yd. per hour.

The volume of water for washing the sand varied from 12 to 14 times the volume of sand washed. In the cost of operation the volume has been estimated at 15 times that of the sand, at a cost of $0.04 per thousand gallons.

Refilling. — 18 550 barrows, 1 630 hours, 21.8 barrows per cubic yard = 0.52 cu. yd. per hour. This work was chiefly done by extra labor.

The average depth of scraping was about $\frac{3}{8}$ inch, computed from the total quantity of sand replaced and the area scraped.

During the periods covered by these scrapings, the filters yielded 1 212 000 000 gallons, an average of 66 600 000 gallons per acre between scrapings. This includes the first run of the filters, when the unnaturally turbid water already mentioned was pumped directly on the beds.

COLOR.

The average color of the Hudson River water corresponds to 0.50 to 0.60 on the platinum scale, and about 40% of this color is removed from the water by the filters.

TURBIDITY.

In periods of freshet the water is very turbid. The highest turbidity reached since the operation of the filter was in December, when the raw water showed 0.60. The effluent then contained 0.008. Generally the raw water runs about 0.035, all of which is removed. The platinum-wire standard is used.

TYPHOID FEVER.

The reason for building the filters was the sewage pollution of the Hudson River, and the large death rate from typhoid fever. The average number of deaths from this cause for the nine years ending with 1898 was 85 per annum. During the four months in which the filters have been in operation seven deaths from this cause have been reported. For the corresponding months of the nine years ending with 1898 the average number has been 24. The deaths from this cause have thus been reduced in the ratio of 24 to 7, and one of these seven was in a family which did not use city water.

MECHANICAL FILTRATION.

BY EDMUND B. WESTON, C. E., PROVIDENCE, R. I.

[*Read January 10, 1900.*]

It is my intention to say a few words this afternoon in regard to the purification of city and town water supplies by the use of sulphate of alumina in connection with the subsidence gravity system of mechanical filtration.

There are other systems of mechanical filtration, which I presume are well known to you; but as the subject is a very exhaustive one, and as my experience in regard to mechanical filtration has been mostly in connection with this system, it is my intention to confine myself to it.

To aid in my explanations, I will show you a number of views illustrating the details of the subsidence gravity filter and its necessary auxiliaries, as well as views of several filter plants which were designed under my direction.

Before going into details, I will first briefly outline the

PROCESS OF FILTRATION.

To the water to be purified is first added the desired quantity of sulphate of alumina in the form of a weak solution. The water then passes slowly through the subsidence basin, where coagulation takes place, or, in other words, the sulphate of alumina is decomposed and a flocculent gelatinous precipitate of aluminum hydrate is formed. This flocculent precipitate surrounds, entangles, and aggregates the suspended matter, bacteria and inorganic substances, and slowly carries them down through the water, and, as a result, the greater part of them are finally deposited upon the bottom of the subsidence basin. Generally speaking, it may be said that the action of the aluminum hydrate is much the same as the action of the white of an egg in clearing turbid coffee. From the subsidence basin the partially clarified water flows to, upon, and through the filter bed, which acts as a strainer and removes the remaining coagulated particles, including bacteria. A further action of the aluminum hydrate is to unite

with the soluble coloring matter in the water, thereby rendering the effluent nearly colorless.

In a very few minutes after a filter is put in operation a thin gelatinous layer is formed upon the top of the filter bed, which adds materially to the thoroughness of the process of filtration.

When the filter bed has become clogged, it is thoroughly cleansed by forcing up through it a reverse flow of water under pressure, a mechanical rake or agitator being operated at the same time, which is of great advantage for the efficient cleansing of the filter bed. When the subsidence basin is washed out, it is done by allowing the wash water, after it has passed up through the filter bed, to overflow through a central standpipe down into the subsidence basin. By a special appliance, the water as it enters the subsidence basin from the standpipe is swashed about the bottom and sides of the basin.

The principal parts of a subsidence gravity filter and the appliances required in connection with the use of sulphate of alumina may be roughly described as: —

1. The apparatus used for the preparation and addition of the sulphate of alumina solution.

2. The subsidence basin in which coagulation takes place, and in which the water is partially clarified by subsidence.

3. The filter bed through which the water finally passes.

FILTER.

Fig. 1 shows a section of a standard 12 foot subsidence gravity filter. Mr. O. H. Jewell, of Chicago, Ill., is the designer of this type of filter. The outside diameter is 13.5 feet; the diameter of the filter bed is 12 feet, and the total height of the filter 16 feet. Its capacity is from 259 000 to 332 000 gallons per 24 hours, depending upon the character of the water. The rates of filtration corresponding are from 100 000 000 to 128 000 000 gallons per acre per 24 hours.

The tanks of the filter are shown to be constructed of wood. They are generally of well-seasoned selected cypress or cedar, dressed on both sides to $2\frac{3}{4}$ inches thick; but they are also built of iron or steel, if desired. Both the main and inner tanks, when of wood, are bound with extra heavy wrought-iron hoops.

The timbers supporting the inner or filter-bed tank are of hard wood, and very large and strong, so that no great weight or strain is

carried on the staves. The upright timbers rest upon a heavy secondary floor, laid upon the bottom of the main tank, for the purpose of distributing the weight.

Diametrically across the floor of the filter-bed tank are laid heavy cast-iron manifold sections, which are held together with machine bolts. The strainer pipes, or branch pipes, which are screwed into these manifolds at equal distances along the same, are of brass or iron, and extend to the side of the filter-bed tank, being cut in various lengths to fit the circle. These pipes are capped on the ends by

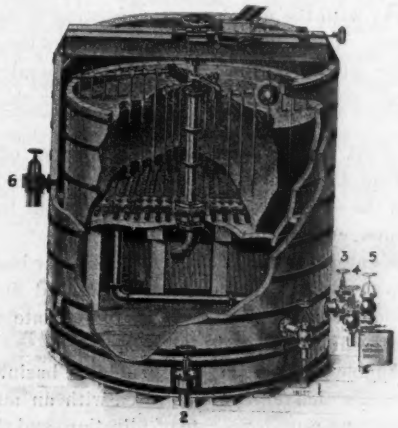


FIG. 1. — SECTION OF SUBSIDENCE GRAVITY FILTER.

reducing elbows. The collecting and wash strainers are evenly spaced along these pipes, and securely screwed into them.

The central manifold is provided with a flange opening to which is bolted a central standpipe that extends several inches above the top of the filter bed.

The stirring apparatus consists essentially of a heavy cross arm, which swings on a vertical shaft extending from the cross beams on top of the filter to the deflecting elbow in the subsidence tank. Into this cross arm are keyed four heavy horizontal shafts, which carry the swinging rakes or bars. These bars are secured in swivel collars, having quadrant lugs which engage the swivel collars when the agitator bars are vertical in the filter bed. These rakes or bars are

arranged to traverse the bed about every three inches, thereby reaching all its parts.

The agitating device shown upon this filter in the cut is a worm and worm wheel, which are combined in one heavy cast-iron casing. The casing provides for a well of oil in which the worm and wheel dip, so that both are continuously running in oil when in operation. The worm shaft is fitted with an end support secured to the cross beams on top of the filter, and is provided with either duplex friction clutches operated with one lever, or tight and loose pulleys with shifter rods if preferred. Other agitating devices are sometimes used that do away with the worm gears, consisting of bevel and spur gears and pinions. These latter devices are always used upon filters having a diameter greater than 15 feet, and I generally recommend their use upon all filters having a filter bed greater than 10 feet in diameter.

The "down draft" or delivery pipe for carrying off the filtered water extends from the bottom of one of the manifold sections to near the floor of the subsidence basin, and thence out from the basin to a "cross" outside of the filter.

The inlet pipe enters on the side of the subsidence basin somewhat above the bottom, and is provided with a balanced float valve connected with a float on top of the filter, to regulate the incoming water and keep the filter uniformly full of water.

There is a manhole for entering the subsidence basin.

The filtered water delivery pipe is fitted with an automatic controller for maintaining a uniform rate of filtration, and through which the filtered water is finally discharged. This device needs no attention whatever and may be adjusted to any rate of delivery desired.

A different controller, of later design than the one shown connected to the filter, is now used, and will be described in detail in due course.

An opening is provided in the "cross" on the outside of the filter to which a steam connection can readily be made for the sterilization of the filter bed, whenever this becomes necessary.

The filtering material is generally from 3 to 4 feet in depth and is composed of crushed quartz or a specially mined sand. The wash and collecting strainers are made entirely of brass, with bronzed screens and deflecting plates, and are all securely copper riveted. There are 444 of these strainers in a 12 foot filter. Each screen has about 900 holes of about $\frac{1}{100}$ of an inch in diameter.

Filters of this design, for the purification of city and town water supplies, have filter beds ranging from 10 to 24 feet in diameter. The capacity for a filter having a bed 10 feet in diameter would be from about 179 000 to about 229 000 gallons per 24 hours, and for a filter having a bed 24 feet in diameter from about 1 000 000 to about 1 319 000 gallons per 24 hours.

VALVES AND CONNECTIONS.

The raw water main for supplying the filters is connected to inlet valve No. 1 (Fig. 1). Valves Nos. 2, 3, and 6 are for washing and cleaning, and are connected to a waste pipe or sewer. Valve No. 4 is connected with a pipe which conveys water for washing the filter bed and subsidence basin. Valve No. 5 is directly connected to the controller, which discharges the filtered water into a flume or clear water basin or reservoir. Valves Nos. 2 and 6 may be placed at any point around the filter, and, in most instances, are placed so as to both discharge into the same waste pipe or sewer. Valve No. 1 may also be located at any desired point around the filter.

WASHING.

To wash the filter, all valves having been previously closed, open washout valve No. 6 wide. This allows all water above the inner tank and in the annular trough to drain out. Then open valve No. 4 slowly until sufficient water is flowing up through the filter bed to render it semi-fluid, thereby allowing the agitator to move easily. When the wash water has begun to flow freely over into the annular trough, the stirring apparatus may be started on the forward motion. The rakes or bars then penetrate the semi-fluid filter bed, and thoroughly agitate and scour the same, the wash water sweeping all the sedimentary matter over the edge of the inner tank into the annular trough, from which it is discharged through washout valve No. 6 to the waste pipe or sewer. From five to ten minutes are usually allowed and found sufficient to completely cleanse all of the filtering material. When the filter bed is sufficiently clean, first reverse the motion of the stirring apparatus while the current of wash water is still on, so that the rakes or bars will come out of the filter bed and rest upon its surface; and while they are running backward slowly close wash valve No. 4; then stop the agitator and close washout valve No. 6.

In washing a filter a pump is generally required for forcing the

water up through the filter bed. The pump can be driven by steam or water power. Steam or water power is also required for driving the agitator.

REWASHING, OR FILTERING TO WASTE.

After the filter has been washed open inlet valve No. 1 slowly, and when the filter is nearly full of water open rewash valve No. 3 one or two turns; when the effluent comes clear and is satisfactory in appearance, close rewash valve No. 3 entirely; allow inlet valve No. 1 to remain entirely open. The object of rewashing or filtering to waste immediately after washing the filter is to displace any turbid or impure water remaining in the filter bed. Filtered water is preferably used for washing. It is obvious, therefore, that this operation is only imperative when the raw water is used for washing, and also that only a minute or two is required to completely displace the turbid waste with pure filtered water. When a filter bed is washed with filtered water rewashing is seldom found necessary.

FILTERING.

After rewashing, open valve No. 5 slowly.

In this operation the raw water, which has been previously charged with the sulphate of alumina solution, enters the subsidence basin through inlet valve No. 1. The water is then slowly circulated around this basin by the deflecting flange on the inside directly in front of the inlet pipe. In this way the incoming water is prevented from causing local or short-cut currents. Subsidence takes place very rapidly, and before the water reaches the upper central discharge from the basin into the standpipe, generally all of the heavy matter and most of the finer impurities, including bacteria, which have been coagulated, are precipitated. It is variously estimated that from 50 to 75 per cent., by weight, of the suspended impurities are caught in this basin alone. Tests have actually proven that from 40 to 80 per cent. of the bacteria have been retained in these subsidence basins. The water after subsidence leaves the basin and rises through the central standpipe and overflows upon the filter bed. A low head of water, generally about 2 feet, is carried upon the filter bed so as to prevent the incoming water from cutting channels or furrows in the bed. The water then proceeds downward through the filter bed, depositing thereon and therein the coagulated

matters, impurities and bacteria, which have resisted subsidence, and thence it is collected evenly and proportionately from all parts of the bed by the strainer system, first entering the numerous strainers themselves, then the parallel branch pipes and manifolds, and finally coming together in one volume in the "down draft" or delivery pipe, which runs directly to the outside of the filter and communicates with the "cross" to which valves Nos. 3, 4, and 5 are attached. From the latter valve it is discharged into the controller, clear and bright.

RATE OF FILTRATION AND TIME ALLOWED FOR SUBSIDENCE.

The rate of filtration, or the velocity of the water when it flows through the filter bed, is generally from about 100 000 000 to 128 000 000 gallons per acre per 24 hours, which corresponds to from 1.59 to 2.04 gallons per square foot of filter-bed surface per minute. At these rates of filtration the time which is allowed for subsidence in a 12 foot filter, or the time that it takes for a quantity of water to flow through the subsidence basin equal to its cubic contents, is from 30 to 40 minutes. In filters of larger diameter, the time is somewhat more.

For water containing large quantities of suspended matter, like some Southern and Western waters, a longer time for subsidence is required than can be had in the filters. This is accomplished by using one or more auxiliary subsidence basins, built independent of the filters proper, of such capacity as the conditions of the case may necessitate.

CLEANING THE SUBSIDENCE BASIN.

This operation is carried on simultaneously with the washing of the filter bed, and the same wash water cleanses both filter bed and subsidence basin. The operation is automatic. In cleansing the basin, valve No. 2, instead of washout valve No. 6, is opened wide and the filter bed washed in the manner previously described. As washout valve No. 6 remains closed, the dirty wash water, instead of overflowing the inner tank and escaping through washout valve No. 6, is compelled to rise above the central standpipe and then overflows down through it into the subsidence basin. At the bottom of the standpipe, the falling water comes in contact with a large open deflecting elbow, which is fastened to the same vertical shaft that

carries the agitator or rakes, and therefore revolves with it, and the water is thrown with considerable violence against the lower sides and bottom of the basin, and is discharged through valve No. 2, carrying with it even the heaviest accumulations of sediment.

STERILIZING.

It has been found advantageous to sterilize a filter bed once in about six months. This is generally done by the use of steam and soda ash. The water in the filter is drained off, with the exception of the water in the filter-bed tank, which is allowed to remain to a depth of about 8 inches above the top of the filter bed. All of the regular valves are then closed, a few pounds of soda ash scattered into the water, and steam let into the filter-bed tank from the sterilizing pipe, through the same interior pipes and strainers where the wash water is let in and the filtered water flows out. The filter bed is then boiled from 30 to 60 minutes. At the completion of the boiling the water is drawn off, and the filter bed is washed in the usual way several times. When the filter is again put in service, the filtered water is allowed to waste for a time through the rewash pipe.

The advantage of being able to sterilize a filter bed is considered to be of great importance.

APPLICATION OF THE SULPHATE OF ALUMINA SOLUTION.

The sulphate of alumina is first dissolved in a mixing tank. Two or more tanks are always used, so that while one is supplying the solution, the operation of mixing can be carried on in another tank. Gages are attached to the mixing tanks so that the quantities of sulphate of alumina solution flowing from them can be accurately measured.

The solution may be fed into the raw water by gravity or by the use of a small auxiliary pump, operated automatically either by steam or mechanical connection to the main pump which supplies the raw water to be filtered, or the pump may be driven by a propeller placed in the supply pipe.

Fig. 2 shows the method of application by the Warren chemical pump. This is of rubber, and has six hollow arms bending at the hub and passing along the pump axis to a deflecting cup, where

FIG. 3.—INTERIOR OF A SUBSIDENCE BASIN.

PLATE I.

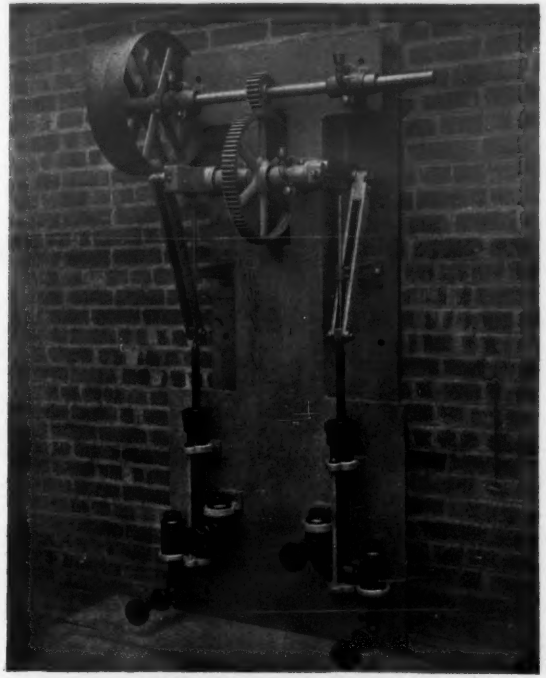


FIG. 1.—CHEMICAL PUMP.

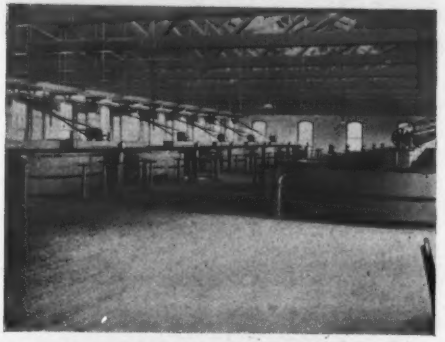


FIG. 2.—OPERATING FLOOR, NORFOLK, VA.

FIG. 3.—INTERIOR OF A SUBSIDENCE BASIN.

the liquid is thrown down into a funnel, from whence it flows through a small pipe into the main pipe that supplies the raw water to be filtered. This pump is driven by a propeller, placed in the main supply pipe. The speed of the wheel, and therefore of the pump, corresponds with the velocity of the incoming water, so that a given standard solution is fed in exact proportion to the amount of raw water being treated.

The pump revolves in a small tank containing the sulphate of alumina solution, and takes up the proper quantity of the solution and passes it into the hub, and thence to the deflecting cup.

By lowering the level of the solution in the pump tank, or by inserting plugs or reducing orifices in the arms of the pump, the

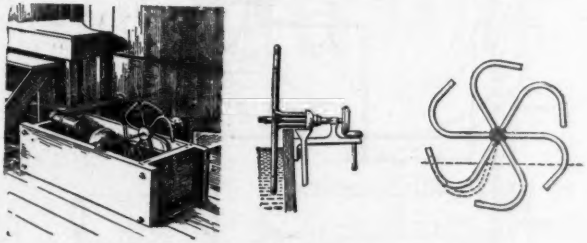


FIG. 2. — WARREN CHEMICAL PUMP.

amount of solution used per gallon of raw water may be varied without changing the strength of the solution.

The sulphate of alumina solution flows by gravity to the pump tank, from the mixing tank or tanks in which it is prepared, through a small pipe. A rubber valve connected to this pipe and a rubber float in the pump tank regulate the flow of the solution into the pump tank and keep it at the desired level.

Plate I, Fig. 1, represents a chemical pump which may be used for feeding the sulphate of alumina solution. It is a single acting duplex pump, and the parts which are exposed to the solution are made of or are covered with rubber. This pump is driven by a belt leading from the main pumping machinery which supplies the raw water to be filtered. The length of stroke is easily adjusted, so that the solution can be applied at different rates if desired.

Fig. 3 shows a method by which the sulphate of alumina solution can be fed to the raw water by gravity. The solution flows by gravity through a small pipe from the mixing tank or tanks to the grav-

ity tank. A rubber valve connected to this pipe and a rubber float in the gravity tank regulate the flow of the solution into the gravity tank and keep the level of the solution in the same at a constant elevation. The solution is discharged into the raw water by gravity from the gravity tank through a pipe which terminates in a small valve, which is arranged so that an orifice of proper diameter can be

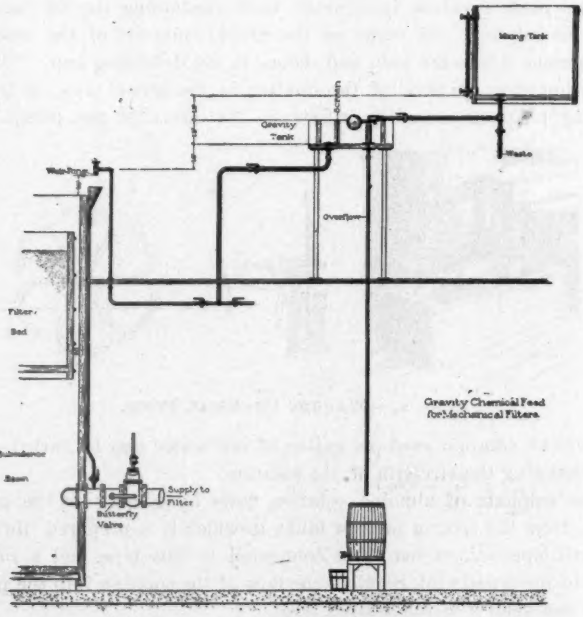


FIG. 3.

attached to it, thereby regulating the discharge to the correct amount. The discharge is into a funnel at the side of the filter, and thence the solution passes down through a small pipe into the supply pipe through which the raw water to be filtered flows. When more than one filter is supplied by this system of gravity feed, a main pipe sufficiently large so that there will not be any appreciable friction when the solution flows through it is run from the gravity tank past the filters, and a branch is laid from this main pipe to each filter.

AUTOMATIC CONTROLLER.

An accurate automatic controller for measuring the flow through the filter fled and keeping it perfectly constant during the process of filtration is of the utmost importance. The two principal reasons for the necessity of an accurate controller are: first, the exact quantity of water passing through the filter bed being known, the cor-

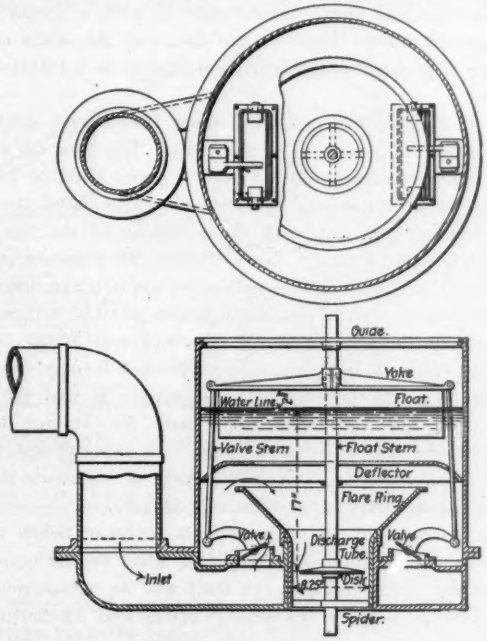


FIG. 4. — AUTOMATIC CONTROLLER.

rect quantity of sulphate of alumina solution can be accurately and uniformly applied to the raw water by gravity or other means; and second, by keeping the flow of water through the filter bed perfectly constant, scouring action in the bed is avoided.

Fig. 4, reproduced from a cut in the *Engineering Record*, shows such a controller.

The controller is connected (outside of the filter) to the "down draft," or delivery pipe, from which the filtered water passes through

butterfly valves in the lower part of the controller. It contains a float mounted on a hollow float-stem operating in guides at the top and bottom. Beneath the float is a deflector, designed to quiet the incoming water and reduce any currents, thereby giving a smooth entrance to the discharge tube, and being aided in this respect by the flaring ring on the discharge tube. Mounted also on the float-stem, so as to be maintained at a constant depth, is a disc which is turned with a thin edge and sharp corners, and of such a diameter as will give the annular orifice between the disc and the walls of the discharge tube a predetermined area proportional to the desired rate of discharge.

The inlet butterfly valves in the lower part of the controller are operated by levers connected to the float. The flow of water from the filter is regulated as follows: With a given head or pressure on the surface of the filter bed and free discharge from the filter, the rate of discharge will vary with the condition of the filter bed. If for a given level of water in the controller the pressure in the inlet pipe be such that more water will pass through the inlet butterfly valves than can be discharged through the annular orifice, the level of the water in the controller will rise, and with it the float, which will tend to close the inlet butterfly valves and throttle the flow until equilibrium is established between the supply to and the discharge from the controller. If, on the other hand, the pressure on the inlet pipe be reduced, and consequently the flow through the valves, the water level falls, and the float falling with it increases the opening of the valves and thus restores the equilibrium.

Should the head on the inlet pipe be reduced below that determined as the minimum limit, the water level in the controller will fall below the minimum limit, the float will be submerged less, and consequently the head on the annular orifice and discharge tube will be diminished below the minimum desired. This will indicate a needed washing of the filter bed, which is generally manifested to the operator by an indicating water gage, actuated by a float in a small vertical pipe that is connected to the inlet pipe of the controller. The rated capacity of discharge may be adjusted by altering the depth of submergence of the disc, or by changing the area of the annular orifice by substituting a disc of different size. Air is admitted below the disc through the hollow float-stem, which has vents below the disc.

Tests have been made with this design of controller under heads

ranging from 0.33 to 18 feet above the level of the water within it. These tests have shown no measurable variation in the discharge.

EAST PROVIDENCE, R. I., FILTER PLANT.

Fig. 5* shows a filter plant at East Providence, R. I., which went into service in March, 1899. The cut shows a longitudinal section through the filter building, showing the filter and auxiliaries

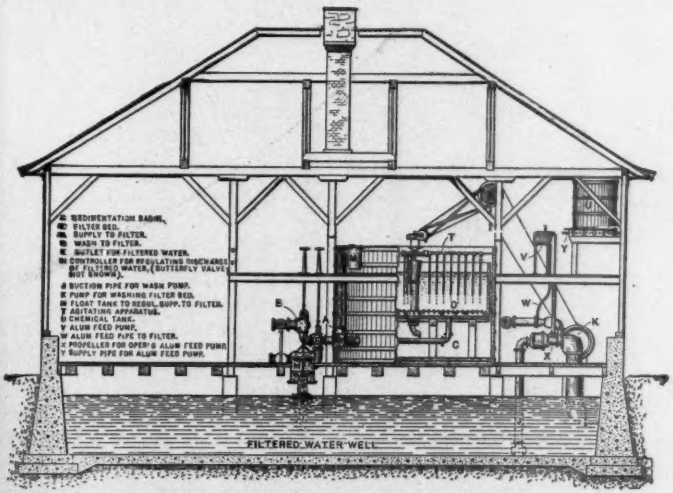


FIG. 5.—EAST PROVIDENCE FILTER PLANT.

and pure water well, including operating floor, chemical mixing tanks, Warren chemical feed pump, wash pump, power transmission, controller, etc. There is one filter. The diameter of the filter bed, which consists of crushed quartz, is 15 feet, and its available capacity is 500 000 gallons per 24 hours, the rate of filtration being about 125 000 000 gallons per acre per 24 hours. The raw water is supplied to the filter by gravity. The filtered water is discharged into a pure water well under the building.

On account of being able to supply the raw water by gravity, the filter is not of the standard height, but is only 12 feet high instead

* Electrotype from cut in *Proc. Am. Soc. C. E.*

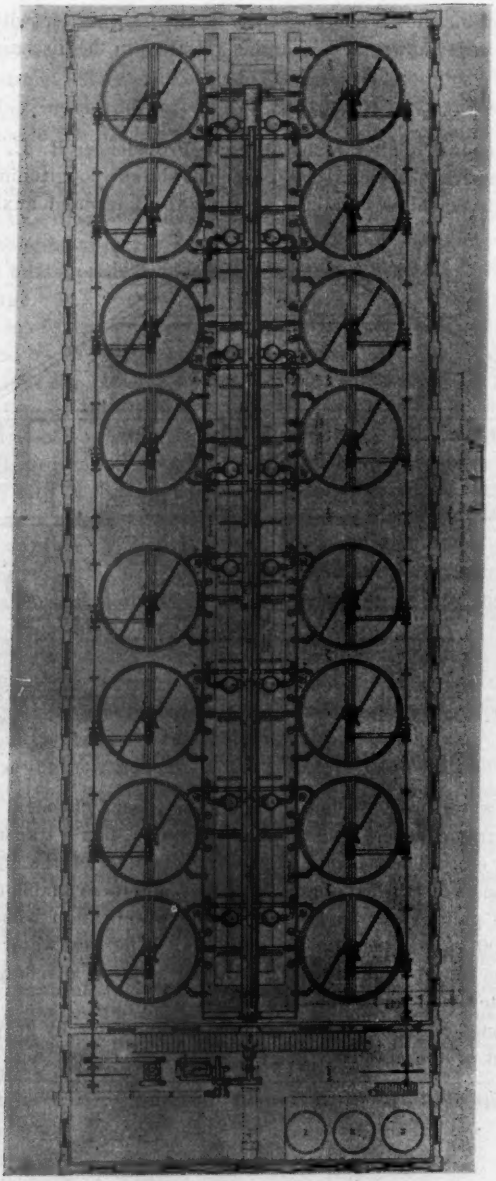


FIG. 6.—PLAN OF FILTER BUILDING, NORFOLK, VA.

of 16 feet, which reduces the time allowed for subsidence in the filter to about 17 minutes.

The power for driving the agitator and wash pump is transmitted by a rope and shafting from a turbine wheel in the adjacent pumping station.

The building is arranged for three additional filters when the requirements of the service demand them.

NORFOLK, VA., FILTERS.

A filter plant at Norfolk, Va., having an available total capacity of 8 000 000 gallons per 24 hours, went into service in August, 1899. This plant is shown in Figs. 6 and 7.

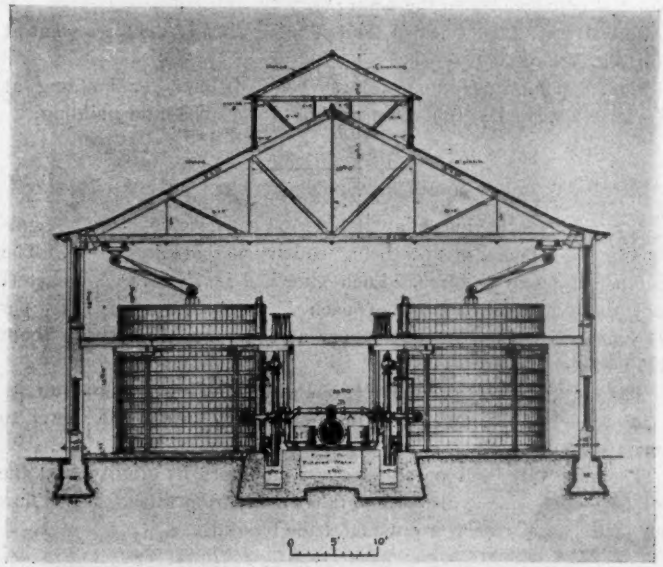


FIG. 7.—SECTION THROUGH FILTER BUILDING, NORFOLK, VA.

The number of filters is sixteen, each of which has a filter bed 15 feet in diameter and of an available capacity of 500 000 gallons per

24 hours. The rate of filtration per acre per 24 hours is about 127 000 000 gallons. The raw water is supplied to the filters by pumping. The filtered water is discharged into a flume, from whence it flows to the pure water reservoir outside of the building.

On account of the peculiar character of the raw water at Norfolk, a longer time for subsidence is required than can be obtained in the filters. This is obtained by using as a subsidence basin a large basin which was formerly used as a reservoir, in which a subsidence of 11 hours or more can be had in addition to the 40 minutes allowed in the filters themselves.

The sulphate of alumina solution is fed from the filter building by gravity, through a small pipe, to the raw water as it flows into a weir chamber at the entrance of the large subsidence basin.

The steam for power is furnished from an adjacent boiler house, which is connected with the main pumping station.

Plate I, Fig. 2, is a view of the operating floor of the filter plant at Norfolk, Va.

Figs. 6 and 7 show an interior plan of the filter building at Norfolk, Va., and a transverse section through the filter building.

ROME, GA., FILTER PLANT.

A filter plant having an available total capacity of 1 500 000 gallons per 24 hours is now being constructed at Rome, Ga. The number of filters is three. Each filter bed is 15 feet in diameter, and the available capacity of each filter is 500 000 gallons per 24 hours, the rate of filtration per acre per 24 hours being about 127 000 000 gallons.

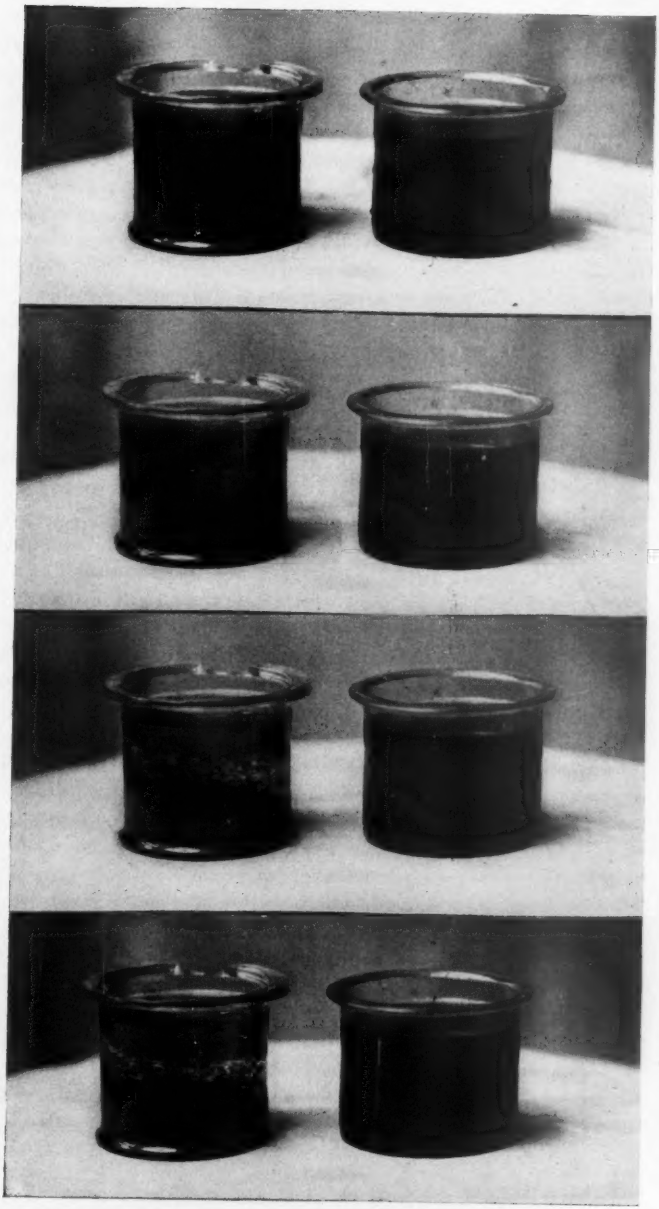
The building is arranged for two additional filters, when required.

A steam boiler is located in the building to furnish the power to operate the filter plant.

The raw water will be supplied to the filters by gravity, and the filtered water will be discharged into a well, from whence it will flow to a pure water reservoir outside of the building.

ARTIFICIAL SUBSIDENCE.

The relatively quick subsidence which takes place in a subsidence basin of a subsidence gravity filter is of so much importance that I will devote a short time to especially describing the process.



PROGRESS OF SUBSIDENCE IN ROTATED AND QUIET WATER.

The water, as it enters the subsidence basin, as has previously been mentioned, is given a circular motion around the basin by the deflecting flange in which the supply pipe terminates. The movement of rotation is more or less coincident with the surface of a cone whose base is the bottom of the basin and whose apex is the central entrance to the standpipe through which the water flows from the basin to the filter bed. The upright timbers which support the filter-bed tank and the pipes in the interior of the basin all tend to produce counter currents and eddies.

The rotary movement and counter currents and eddies bring about a much quicker subsidence than would be the case in a stationary tank or in a straight unobstructed current of water, as they cause the coagulated particles to meet with and overtake each other, and they are consequently thrown into juxtaposition, thereby forming much larger masses of greater specific gravity.

The next five views are intended to illustrate the practice and theory of the method of subsidence which I have just mentioned.

Plate I, Fig. 3, is from a flash light photograph that was taken of the interior of a 12 foot filter subsidence basin, which is one of a plant of eighteen, in service at Elmira, N. Y.

The upright graduated sticks were inserted in the deposit at the bottom of the basin for the purpose of measuring its depth. As will be seen, it is much higher in the center than it is near the circumference. The time allowed for subsidence was about 33 minutes, and the deposit shown is the amount collected during a seven days' run of the filter.

The casting shown at the top of the view is the rotary deflecting elbow, secured to the central shaft below the standpipe, which is used when the subsidence basin is cleaned. The view also shows the main delivery pipe for the filtered water.

The four views on Plate II are intended to illustrate the theoretical side of the question. They were made from photographs which were kindly loaned me by Prof. W. P. Mason, of Troy, N. Y., and which were taken during an experiment conducted by him.

These views show the progress of subsidence in two jars of water during the experiment that I have just referred to. The jars differ from each other only in the fact that the one on the left had its contents gently rotated during the experiment, while the right-hand jar was maintained at complete rest. The same quantity of hydrate had previously been formed in each.

The views show how progressively advantageous was the rotary motion for the formation and deposit of large masses of hydrate. The first view was taken immediately before the rotary motion was commenced in the left-hand jar; the second shows the jars three minutes after the rotary motion was commenced; the third was taken six minutes after the rotary motion was commenced; and the fourth view, which completes the series, shows the jars ten minutes after the rotary motion was commenced in the left-hand jar, and shows that subsidence in the latter jar was somewhat further advanced than it was at the end of six minutes. It also shows that, apparently, there had not been any subsidence in the right-hand jar, in which the water had remained stationary during the entire experiment of ten minutes.

RESULTS.

Probably the most extensive test of a mechanical filter in practical operation that has ever been made in this vicinity was conducted during the months of March, April, and May, 1899, with the filter of the East Providence Water Company, at East Providence, R. I.

The average results obtained during this test, when sulphate of alumina was used at the rate of one grain per gallon, show that there was: —

99.2% less bacteria in the filtered water than in the raw water;
6% less total solids;
1% less chlorine;
61% less ferric oxide;
38% less aluminic oxide (alumina);
29% less free ammonia;
63% less albuminoid ammonia;
83% less color;
20% increase of total hardness in the filtered water.

The filtered water in every instance was distinctly alkaline.

The increase in the total hardness, 20 per cent., is, of course, of no particular moment, as it is only equivalent, expressed as calcium carbonate, to 0.21 of a grain per gallon, and, relatively, the effect of so small an amount would not be noticed, either in the formation of boiler scale or in the quantity of soap used for domestic purposes.

The question is sometimes raised, in the course of preliminary investigations, as to the relation between the alkalinity of a natural

water and mechanical filtration. I will endeavor to state briefly my understanding in regard to it.

Alkalinity is generally expressed as calcium carbonate or carbonate of lime. When a proper quantity of sulphate of alumina is added to a natural water containing an alkaline substance, for example, carbonate of lime, an exchange takes place. Instead of sulphate of alumina and carbonate of lime, there is produced carbonate of alumina and harmless sulphate of lime. But the carbonate of alumina immediately decomposes, giving off carbon dioxide, and forms aluminum hydrate, which acts as a coagulant, as I have before stated.

I am led to believe, more especially in regard to New England natural waters, that reliable experimental results are much more satisfactory than theoretical computations for drawing conclusions as to the relative alkalinity that it is requisite for a natural water to have in order for it to properly act with the added sulphate of alumina.

At East Providence the sulphate of alumina used during the test contained about 22 per cent. of alumina (Al_2O_3). The alkalinity, expressed as calcium carbonate in parts per 1 000 000, during the test averaged 11.9 for the raw water and 4.6 for the filtered water. The average alkalinity of the raw water in March was 7.1, in April 11.0, and in May 14.4.

In every instance during the test, as I have already stated, the filtered water was distinctly alkaline, and therefore showed that more sulphate of alumina could have been added to the raw water than the one grain per gallon that was used.

As it may be of interest, I will call attention to the alkalinity of the water supplies of Pawtucket, R. I., and Providence, R. I., which was determined during March, April, and May, 1899, coincident with the analyses that were made of the raw water at East Providence, for the purpose of comparison.

The total average alkalinity of samples of water from the intake at Pawtucket during the three months was 12.2. The average for March was 7.8, that for April 11.9, and that for May 15.1. As can be seen from these figures, the alkalinity of the Pawtucket raw water was somewhat greater than that of the raw water at East Providence.

The total average alkalinity of samples of water from the settling basin of the Providence water works, which is supplied with water

from the Pawtuxet River, at Pettaconset Pumping Station, during the three months was 8.8. The average for March was 5.2, that for April 8.7, and that for May 10.2. These figures show that the alkalinity of the Providence raw water was less than the alkalinity of the East Providence and Pawtucket water. It is possible, however, that if the samples of water had been taken from the Pawtuxet River itself instead of from the settling basin, a higher alkalinity would have been obtained, as there are several large springs at the bottom of the settling basin.

The question is sometimes asked if mechanically filtered water will injuriously affect steam boilers and iron pipes.

As a matter of fact, there are in the United States alone more than 127 mechanical filter plants in operation, purifying the water supplies of cities and towns. These represent a total daily capacity of more than 220 000 000 gallons, yet I have never heard of a case where the mechanically filtered water has in any way injured steam boilers or iron pipes.

The quantity of sulphate of alumina used in purifying a water is relatively very small. It may be said that, on the average, it ranges from ¼ of a grain to 3 grains per gallon, dependent upon the character of the water — and the character of the water is generally dependent upon the place. At East Providence the maximum amount used is 1 grain per gallon.

Some persons have feared that the use of mechanically filtered water might in some manner be injurious to health. I would say that I have never known of an instance of this kind.

In August, 1898, Dr. Gardner T. Swarts, Secretary of the State Board of Health of Rhode Island, sent circular letters asking for information in regard to the use of sulphate of alumina, to the health officers of different cities and towns where mechanically filtered water is used. Among the questions included in each circular letter was the following: —

"Has any sickness among the users of water been attributed to the sulphate of alumina in the water?"

The number of replies received to these circular letters from cities and towns where sulphate of alumina or alum had been used from about 1 to about 17 years was 44; and the reply to this question in every instance was in the negative.

Practically all natural waters appear to contain in solution some compound of alumina.

Several years ago a sample of sulphate of alumina weighing one half of a grain was analyzed. At the same time a sample of Pawtuxet River water, which is the source from which the city of Providence obtains its supply, was analyzed. The results indicated that the sample of Pawtuxet River water contained in solution, per gallon, 37 per cent. as much alumina (Al_2O_3) as the sample of sulphate of alumina.

It has sometimes been stated, apparently as a sort of bugbear, that mechanically filtered water may contain sulphuric acid. This statement is probably based upon an ambiguous use of the term "sulphuric acid." Such a water may contain sulphates, but these are not sulphuric acid, although they may be considered as representing it. These sulphates are harmless. They are present in the Pawtuxet River water, and can probably be found in nearly all natural waters.

The Commission to Investigate the Extension and Improvement of Philadelphia's Water Supply, in a report dated September 15, 1899, state in regard to mechanical filters, to the effect: By virtue of some operation not yet thoroughly explained, mechanical filters appear to be able to secure equally as satisfactory bacteriological results as slow sand filters, although filtering at from thirty to fifty times the rate. In other words, for a quantity of water requiring from thirty to fifty acres of filter beds by the slow sand process, one acre of surface of mechanical filters would suffice, provided the conditions of the given case were equally favorable to the two systems.

COST OF FILTRATION.

I have quite recently estimated $4.73 per million gallons as the cost of operating and maintaining a mechanical filter plant of 15 000 000 gallons per 24 hours available capacity, while using 0.6 of a grain of sulphate of alumina per gallon, and including interest and sinking fund, etc., namely: —

Sulphate of alumina, 0.6 of a grain per gallon, at $1.25 per 100 pounds, for water and wash water	$1.13	per million gallons.
Labor and fuel, etc.	1.63	" " "
Interest, sinking fund, etc.	1.97	" " "
	$4.73	" " "

DISCUSSION.

THE PRESIDENT. The discussion of Mr. Weston's paper will be opened by Dr. Gardner T. Swarts, Secretary of the State Board of Health of Rhode Island.

DR. SWARTS. It is with considerable diffidence that I enter upon this discussion; but, as I presume I am merely a valve-opener for what will come afterwards, I may be excused if I do not go into the detail of this subject as thoroughly as may be done by others who will follow me. My diffidence comes from the fact that there are persons here with us this afternoon who can speak with high authority, and whose experience with mechanical as well as sand filtration is so far in advance of my own that any allusion to the comparative values of this form of filtration and any other, or to the certain peculiar processes which have been spoken of in the paper, and the various matters of detail, can perhaps be better made by them than by me.

But speaking from the standpoint of the public health, I think I may be justified in saying that there is no question which is of more importance to us as health officers and to you as engineers and water works men than this subject of filtration. Fortunate is the city or town that has been able to find within a proper district, at a proper distance from its pumping station or from its center of population, a supply of water which is pure in every particular. If we have to go a long distance to get pure water the expense is so great that we are led, perhaps, to take water from a nearer source, although the quality may not be so good. We have, perhaps, already established a water supply, and too late in the day we find that our dear neighbor above us has had water before and found it must get rid of its wastes and is emptying its sewage into the source from which we take our supply. Of course they have no right to do that, and we have a legal redress, but by the time that can be availed of perhaps the mortality statistics will be increased within our own town to an alarming extent. And we are perhaps justified then in availing ourselves of some means whereby we may purify the water so that we can continue to use it, although it is not as pure as it ought to be in the beginning. And it is by such means as those which have been shown here this afternoon that such a result may be effected.

From what we have heard in the paper it appears that mechanical filtration does, can, and will purify a water which is badly polluted.

As has been stated, an efficiency of 99 per cent. is secured in the removal of bacteria, and that, gentlemen, when we consider that there may be from 3 000 to 6 000 bacteria to a cubic centimeter, and even more, is something worth considering. The number of bacteria may not, of course, represent absolute danger at the time when the bacteria are introduced into the supply, but it means that at some time or other, if there is pollution, there may be organisms which will be dangerous to those who drink the water. Of course we look upon the danger as being principally from typhoid fever or from cholera, two things which perhaps are not so common as we might expect; but the fact that a certain amount of pollution is present indicates that there are other bacteria, which are in the waste products of the human system, as well as the results of decomposition of materials which are going into the sewage of the towns above us and finding their way into our water supplies, or which are being thrown upon the land in the form of fertilizers and thence are washed into our reservoirs, and which we cannot control. And many of those germs, finding their way into the intestinal canal of a human being, will eventually produce, in a debilitated state of the intestine, a form of fever and a form of disease, which, although it may not be true typhoid fever and may not always be due entirely to the presence of the *Bacilli Coli Communis*, will yet produce a condition within the intestine which may result in what we call slow fevers — fevers of indefinite diagnosis which will be sufficiently disturbing to keep us from our business, or reduce our ability as citizens who should be carrying on our business in a proper manner; and such sources of pollution, of course, should be removed. And if it is possible by mechanical or any other form of filtration to so remove that material, of course it is our duty as health officers, as civil engineers, and as water commissioners, to recommend that some system of the sort should be adopted.

The question is not whether we can stop the pollution so much as it is whether we can reduce it by means of purification. And this question does not come alone to us as health officers and as civil engineers. It comes also to individuals who are owning private water supplies, and at times when they are in such a financial condition that they do not care to go to the expense of the purification of the water. They are always liable, even when they have obtained a source of supply which was originally pure, to danger from some new town locating above that supply and polluting the water. And

to them this subject is of much interest. And it is of interest to us as health officers, who must demand from these private corporations that are selling water, or from any city that proposes to sell water, that they shall sell the best that can be had or produced from available sources.

Now, we are assured, and we will assume and believe that water may be purified by mechanical filtration to the extent stated. But the bugbear which is brought up to us by the laity, that is, by the people at large, and by many physicians who have not looked into the subject thoroughly, is that there is great danger that we are going to get alum into our intestinal canals and our stomachs, that we are to be ossified in time, that dire results are to occur as the result of the constant ingestion of alum into the system. If we look back to the time when we were boys, when some of us had the habit of chewing gum and perhaps some other bad habits, we may remember that it was the custom of some boys to carry chunks of alum in their pockets and to chew from them from time to time. I do not remember during my medical experience personally, or from any literature which I have read, to have observed any ill results coming from the use of alum in its crude state.

And, as has been stated in the paper, with a view of determining for the city of Providence whether it was safe to recommend mechanical filtration as a means of purifying the water for that city, I communicated with some thirty or forty different cities, requesting the opinions, not of owners of filter patents or filter plants, not of the mayors or the boards of aldermen, but of the health officers, the disinterested parties who should know of these matters, asking them if they had ever heard of any injury coming from the use of alum in the water, where it was being used in this form of filtration. In no single instance was an affirmative reply received. It was even stated by some that although they were aware that at times there were large quantities of alum in the effluent water, yet they had never known of any disease which they could attribute to that cause. In fact, I have been unable after questioning my various medical friends, and chemists who are also physicians, to obtain any knowledge as to what would actually be a poisonous dose of alum. I have not been able to find any one who would say that even one grain of alum per gallon, if taken in that quantity, was injurious to anybody. Of course it may be objectionable to the taste, and there would be an objection to the use of it by certain persons; but we are informed

that by this means of filtration, if it is properly carried out, no alum passes through the filter into the effluent. The statement is made, and it is confirmed by many experimenters, that there is frequently less alum in the filtered water than there is in the original water before it goes into the filter. Of course that is a statement which ought not to be made too publicly, because it would be said the thing is altogether too perfect, and the statement would be characterized as a little fishy.

As a matter of fact, we want to come down to the practical question, can this system be used? There may be other systems which are good, and all may be of equal value; but in using this system the question is, can we use it with safety? As a health officer, I do not hesitate to recommend this form of filtration, judging from the reports which have been given of the various experiments made by many men who are here to-day, experiments made at Louisville, Cincinnati, Pittsburg, and other places; and I do not think that any of you would hesitate, after looking over the matter, to recommend the system in the same way.

As to the questions of cost or of operation, of course I am not prepared to state. As to the practicability of it, from the numerous illustrations we have had here it would seem that mechanically there can be all manner of devices and wheels and cogs and methods of applying the alum and all that, and that should not be an obstacle. Of course the question of the application of the alum is a thing which has to be considered in the operation of the plants. That, of course, must be accurate, and it can be made accurate, as I believe has been shown; and if that is the case, I see no reason why we should not consider the system favorably.

Mr. George W. Fuller. I have listened with a great deal of pleasure to Mr. Weston's paper. I think it is about the first time there has been presented to this Association a paper describing in detail the construction and operation of the type of filters of which this system is representative. Owing to the lateness of the hour, there are very few points which I have time to bring up to-day. There is one feature, however, which attracted my notice as the paper was read and the views were presented on the screen, and that is the automatic controller. There is no doubt of the advantage, from many points of view, of having the rate of filtration under accurate control, and this controller which has been designed by Mr. Weston appears in every way to serve this purpose in an admirable

manner. I understand from the paper that this gives practically a constant rate of filtration when the head on the controller ranges from 18 feet down to 0.33 of a foot; and I would like to ask Mr. Weston if the uniformity in the rate and the accuracy of the results are maintained as this small head is secured upon the butterfly valve. That 0.33 of a foot refers to the pressure on the butterfly valve, does it not?

MR. WESTON. The 0.33 of a foot represents the distance above the water line in the controller.

MR. FULLER. What pressure would that be on the butterfly valves?

MR. WESTON. When the head is 0.33 foot above the water line in the controller, I should say it would be about 4.5 pounds upon each valve.

MR. FULLER. Another point is with reference to the effect of the rotary movement of the water in this type of a settling basin. Theoretically there is no doubt that the rotary action accomplishes a good deal towards aggregating these particles into larger masses and doing it more quickly than quiescent subsidence, or subsidence in the absence of this rotary movement. The question of how much practical good is accomplished in this manner is a matter which is not clear to me, especially with different kinds of water. It is a matter of a great deal of interest, and if Mr. Weston can give us more information upon that point I think it would be very much appreciated.

MR. WESTON. I think Mr. Fuller is as conversant with that subject as I am, and what experience I have had I have given to you.

MR. FULLER. You mentioned, I believe, the figures from 40 to 60 per cent. of removal of suspended matter. Was that with this rotary motion?

MR. WESTON. I beg your pardon. I stated that it had been estimated that from 50 to 75 per cent. of suspended impurities are caught in the subsidence basins. It was found at East Providence that there was removed in passing through the subsidence basin from 60 to 88 per cent. of the bacteria, averaging about 75 per cent. So far as subsidence is concerned, my personal experience has been mainly with Eastern waters.

MR. FULLER. So far as I know, there has never been any opportunity to compare directly and side by side with the same water, to say nothing of comparable data for a wide range of waters, the effi-

ciency of quiescent subsidence and subsidence under the rotary movement, which is supposed to aggregate more rapidly the suspended particles. While the latter may accomplish a great deal of good, to me it is a matter of considerable doubt from a practical standpoint, although not at all so when considered theoretically.

Dr. Swarts spoke with a great deal of truth, I think, and a great deal of clearness, on the question of undecomposed alum appearing in the filtered water. I can hardly agree with him in all particulars, however, although my opinion, so far as I have been able to study the evidence, coincides in general terms very closely with his. That is to say, in the 130 or more purification plants in operation in this country, using this general type of filter, there seems to be no evidence, so far as I have been able to learn, of their getting into trouble from having undecomposed alum in the filtered water. There are probably times when the alum might be present to a very small degree, if it were expressed in terms of greatest precision. And if we had means of finding out, perhaps, what its exact action in minute quantities would be on service pipes of various metals, or in retarding digestion, our views might be modified. But whether a certain kind of food is digested in sixty-eight minutes or seventy-four minutes is not a matter of vital consequence. The point to which I do attach the greatest importance, however, and upon which, perhaps, I am not exactly in accordance with Dr. Swarts' views, is the absolute absence, under all conditions and at all times, of the undecomposed alum or coagulating salt in the filtered water. In the great majority of the water supplies in this country there is probably very little doubt that this method could be used without getting any undecomposed alum in the effluent.

The question of the use of alum in connection with the water supplies of the East, in which the water is likely to be highly colored (due to dissolved organic matter), and where the alkalinity is fairly small, I think is a matter worthy of careful study. I believe that a great many people have a strong desire to have supplied to them from municipal water supplies a water which is lower in color than that which would be afforded by many Eastern supplies, even after filtration through sand filters. The question of how much color in filtered water is permissible in a water which shall be satisfactory to those who have a considerable appreciation of the æsthetic, as well as to those who wish to use the water for commercial purposes, for boiler supplies and street sprinkling, etc., I think is something

which this Association could discuss to a great deal of advantage. The Western waters have a great deal of silt and clay in them, and after that has been removed, as it is in a great many households by the use of Pasteur filters, they are practically colorless — not absolutely, but practically, colorless, and much freer from color than our Eastern waters. The Western people, in many instances, get accustomed to colorless water, and they are very much surprised at the color in our Eastern waters, and think there is an opportunity for improvement in that direction, independent of the quality of the water so far as it affects the public health.

It is quite interesting to note the points of view of gentlemen who are engaged in the water works business in different parts of the country, where the kinds of water are very different, and where the plants to purify the waters differ in many ways; and it occurs to me as a point which is to be borne in mind that those conditions which are satisfactory and those means which yield satisfactory results in one country, or one part of a country, will not necessarily do so in others. In considering the practicability of one method of water purification, or of one type of filter, it is to be borne in mind that while in many cases it might serve very admirably, in others it might not. In connection with this type of filter, which has been so well described by Mr. Weston, I must say it certainly is entitled to a great deal of credit because of its successful operation in a large number of cities and towns in the country during the last few years. It has been shown, not only by careful tests conducted with such scientific accuracy as can be commanded at the present time, but also in the actual filtration of water for many of these towns, that it is worthy of careful attention. Whether it can be successfully operated in certain parts of the country, in Florida or Maine or New York or Missouri, depends largely upon the water with which it has to deal. We must adjust our means of purification to the water we have to deal with.

Mr. R. S. Weston. I think we have all been very much interested in hearing of these later developments, representing the latest designs in the mechanical system of water purification. I think Mr. Weston will support me in saying that no one design of filter can be applied to all conditions. For instance, a filter which will handle the muddy water of the Ohio River certainly will not handle, with the same method of operation, the highly colored water of Maine, or of some of the tamarack swamps of north-

ern Wisconsin. I cannot see, and I think Mr. Weston will bear me out in this also, that a standard design of filter is a thing to be desired, any more than a standard design of pump. We expect to have a pump for high service and a pump for low service, and we should expect to have a filter for muddy water and a filter for highly colored water, and perhaps a filter for clearer water containing sewage pollution and the bacteria which cause disease.

There are a few things in the design which especially need to be varied to meet local conditions. One of the principal things which suggests itself to my mind at present is the size of the settling basin. This settling basin is the basin in which coagulation takes place. It is the basin, in other words, in which the sulphate of aluminum acts upon the particles of clay in the water, bringing them into aggregates, or it acts upon the dissolved clay in the water, making the dissolved clay unite with the precipitated hydrate of aluminum, or it is the place where the heaviest particles in water are deposited. Therefore, as waters vary in composition, the settling basin, I think, should be of a size adapted to local needs. For instance, I found in experiments which I conducted last year for the Superior Water, Light and Power Company, in Wisconsin, that a period of coagulation of twelve hours using four grains of sulphate of aluminum per gallon of water was not sufficient to satisfactorily coagulate the water. In recent experiments in Washington, D. C., under the direction of Lieut. Col. A. M. Miller, we have found that a period of fifteen minutes often suffices. This goes to prove that the basin must be adapted to the local conditions.

In Mr. Weston's design, the effluent often runs into an open conduit, without any protection against particles of outside pollution from careless workmen, etc. I do not see why our plants cannot be designed so as to obviate this danger. Personally, I prefer the introduction of the coagulant by gravity into the filter, and I think Mr. Weston has shown a very ingenious device for accomplishing this end. I think we are indebted to him for his paper.

Mr. E. B. Weston (by letter). I have already stated in my paper, namely: "For water containing large quantities of suspended matter like some Southern and Western waters, a longer time for subsidence is required than can be had in the filters. This is accomplished by using one or more auxiliary subsidence basins, built independent of the filters proper, of such capacity as the conditions of the case may necessitate."

All of the open flumes that have been shown are arranged so that they can be covered or arched over. I have found, by experience, that when it can be satisfactorily accomplished, open flumes are the most popular with water works officials, as the filtered water can then be seen as it is discharged and flows away from the filters.

ELECTROLYSIS FROM FACTS AND FIGURES.

BY E. E. BROWNELL, ELECTRICAL ENGINEER, DAYTON, OHIO.

[*Read January 10, 1900.*]

The subject of electrolysis from the grounded currents of the single trolley system of electric street railways is one that has recently been very generally discussed, and many plans have been proposed to overcome this destructive action which is to-day so threatening to our water works. None of these plans has ever fully materialized, and it is with some hesitancy that I present this paper before your Association, from the fact that so much has been said and so little done. I therefore wish to call your attention to this important subject in as practical a manner as possible, not in behalf of any corporation or municipality, but upon the merits of the case, as shown by facts and figures obtained from my own experience.

It is an undisputed fact that unless radical measures are adopted by the electric street railways in caring for their return currents, *electrolysis will occur* upon the piping systems wherever the single trolley system, or that which depends upon the rails for return conductors, is used.

Until recently it has been considered that the part of a piping system which was of a higher electrical pressure than, or positive to, the return conductors of the street railway system was the only part that was in immediate danger from electrolysis; but recent investigations have proved that even in the negative area serious electrolytic action has taken place upon cast iron pipes at the joints, and also upon the lead calking, and its effects are especially noticeable upon the surface of contact between the lead calking and the pipe.

It is not the intention of this paper to condemn the street railways, but only to present the actual conditions under which the ordinary electric road is now being operated; and these show that the destruction and resulting dangers are due to defective electric street railway construction. A brief consideration of the present method of construction of the return circuit will show some of the reasons why the current escapes from the rails. When large rails are perfectly bonded

electrically at the joints they offer an easy path, as return conductors, for a current of several thousand ampères, but poor bonding as a general thing results in making them very poor conductors. For instance, a 90-pound girder rail is usually bonded with from one to three .0000 copper bonds, while to make the conductivity of the bond equal to that of the rail would require at least nine .0000 copper bonds, even if perfect electrical contact between bond and rail were obtained. I have found from my own tests upon thirty-seven different electric street railways that the conductivity of the bond varied from 15 per cent. of that of the rail down to zero. In four cases, where the cast-weld joint had been very recently introduced, the conductivity of the joint was 7, 8, 9, and 11 per cent. of that of the rail.

The electrical resistance of a 6-inch water main is found to be 145 times that of a perfectly bonded 90-pound rail, or 580 times that of a double track (four rails); a 20-inch main has 12 times the resistance of the rail, or 48 times that of the double track; and a 36-inch main 2.7 times that of the rail, or 10.8 times that of the double track. In these three mains it was found that an average of 87 per cent. of the total resistance of the pipe lines was in the joints, due principally to the poor electrical contact between the iron and the lead. The maximum resistance of a joint in a 6-inch water main was found to be 0.0367 ohm, or equal to that in 102 lengths (1 224 feet) of the pipe itself.

Plate I, Fig. 1, shows a 90-pound rail with a copper bond of the size necessary to offer no more resistance than the rail itself, *i. e.*, .00 000 545 ohm per foot; also a 6-inch water main, having a resistance of .0003 ohm per foot for the straight pipe.

The resistance of cast iron has recently been shown to be 56 times and that of lead 12 times as much as that of commercial copper. The first of these values was obtained by Prof. Lucien I. Blake, of Kansas City. It is evident, therefore, that a pipe line ought to be a much worse conductor than the track. In fact, to offer no more electrical resistance than a double track laid with 90-pound rails perfectly bonded, a pipe would need to be large enough to drive a team through. Regarding the possibility of constructing a rail bond of a conductivity equal to that of the rail, it may be said that there is at least one bond (the Edison & Brown) which is guaranteed to offer no greater resistance than the rail itself.

The following are a few examples of the actual conditions existing at present.

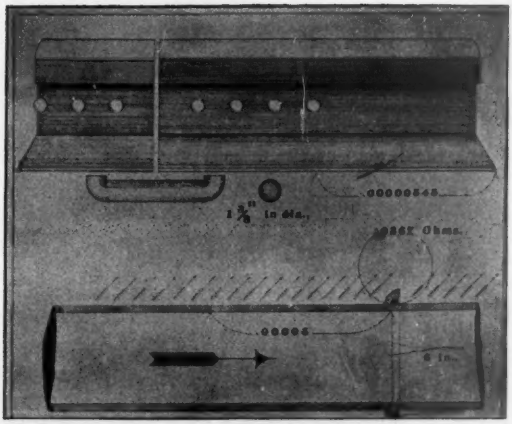


FIG. 1. — RELATIVE RESISTANCES OF 90-LB. RAIL AND 6-IN. WATER MAIN.

FIG. 2. — EFFECT OF ELECTROLYSIS ON CAST-IRON GAS MAIN.

FIG. 3. — EFFECT OF ELECTROLYSIS ON CAST-IRON GAS MAIN.

In one Indiana city, where four 90-pound rails were found by measurement near the power house to be carrying not over 200 ampères each, the loss of potential in four miles was found to be 145 volts. With perfect bonding this should not have been over 23 volts, and probably not over 20 volts, allowing for the decrease of current as the distance from the power house increased. In another part of the same city, where the rails should be carrying a current of some 500 ampères, only 15 ampères could be accounted for. What became of the rest of the current?

In another city in Indiana the rails were found to be returning no current at all, on account of insufficient bonding.

In a certain city in Michigan, the inadequately bonded rails are supposed to care for a return current which amounts, as a momentary maximum load, to 13 000 ampères. This is certainly an imposition.

Figs. 2 and 3, Plate I, show the effects of shunted circuits around the joints of cast iron gas mains. The pipe in Fig. 2 was carrying a current of 50 ampères, and was 1 volt negative to the rails and 1.2 volts positive to the water pipes. The pipe in Fig. 3 carried a current of 120 ampères, was neutral to the rails, and 1.2 volts positive to the water pipes.

The figures on Plate II show the effects of electrolysis upon water pipes. Fig. 1 shows a 6-inch pipe which was 3 850 feet from the power station, and positive by 1.2 volts. The pipe was softer than lead, but contained only one hole. Fig. 3 shows the condition of several miles of water main in Dayton, Ohio, recently abandoned; the pipes were positive, from 5 to 7.2 volts, and carrying a current of 320 ampères. The deterioration was so bad that in places 6-inch pipes weighed less than 10 pounds per foot. Fig. 2 shows the effect of electrolytic action around a screw joint in a wrought iron or steel pipe. This pipe carried a current of 30 ampères, and was 150 feet distant from the street railway and negative to it. The resistance of this joint is equal to that of 2.8 feet of the straight pipe.

It is indeed questionable whether a single trolley electric railway system, in a city as large as Detroit, for example, can ever be provided with a satisfactory return system without incurring an expense sufficient to completely install an insulated return circuit, such as is used in the double trolley system, and thus remove all liability of further electrolytic action.

Take the case of a double track laid with 90-pound rails perfectly bonded, and a 36-inch water main parallel to the track, 5 feet below

the surface and 8 feet from the nearest rail. The water main would even in this case return 10 per cent. of the total current of an ordinary electric railway, with no other pipes in the street. With a wrought iron gas pipe of the same size, having screw joints and under the same conditions, it is safe to say that from 30 to 40 per cent. of the current would follow the pipe, although the resistance of the screw joint is equal to that of 2.8 feet of straight pipe. It is therefore evident that something more than perfect rail bonding is necessary; some sort of a return feeder system of still lower resistance is required, if the single trolley system is to be maintained without injury to gas and water pipes.

The main object should be to keep the pipes as much isolated from the rails and return circuits as possible. Under no consideration whatever should the pipes be metallically bonded to the rails or to the negative pole of the dynamo; for if this is done a larger portion of the current is induced to return by the pipe, as the total resistance by that route is thus decreased. Trouble will then result where the current passes from the pipe to the rail or from one pipe to another, and also from shunted circuits around each joint.

Very serious results have ensued in negative areas where it was until very recently supposed that no danger existed. In Indianapolis the water pipes have the lowest potential but highest resistance of any of the return conductors. Thus it frequently happens that a current is flowing from the gas pipes to the water pipes. The resulting electrolysis upon the gas pipes has caused very serious damage, and not alone in streets used by the electric railway. The highest difference in potential noted between the gas and water mains was 4.2 volts.

The greatest objection to allowing any piping system to act as a return conductor, if it is negative to all other return conductors, is that electrolysis will take place at the joints. I have noted this action in the negative district in sixteen cities. In some cases the pittings were extensive, and reached to one half the thickness of the metal.

From records kept in six different cities, it appears that 97 per cent. of all the leaky joints occurred where the pipes were carrying considerable current.

I have several times noticed the serious effect of electrolysis upon the interior of cast iron pipes. These cases, however, occurred only where the pipes were suspended in the air or surrounded by a dry, sandy soil, and it is evident that the path of least resistance for the current around the joint was through the water in the pipe.

PLATE II.

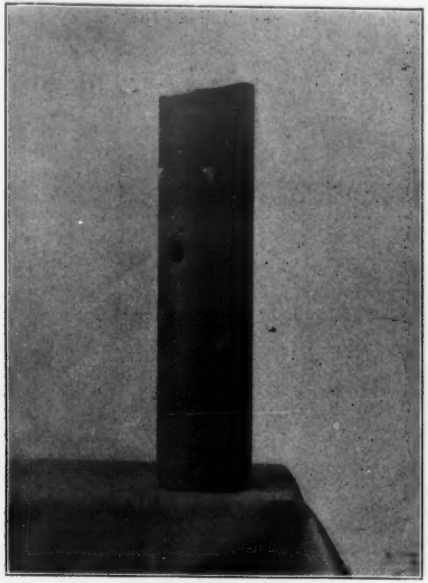


FIG. 1. — EFFECT OF ELECTROLYSIS ON 6-IN. WATER MAIN.

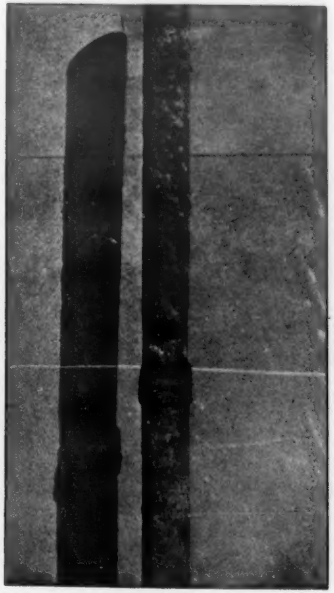


FIG. 2. — EFFECT OF ELECTROLYSIS ON WROUGHT-IRON GAS PIPE.

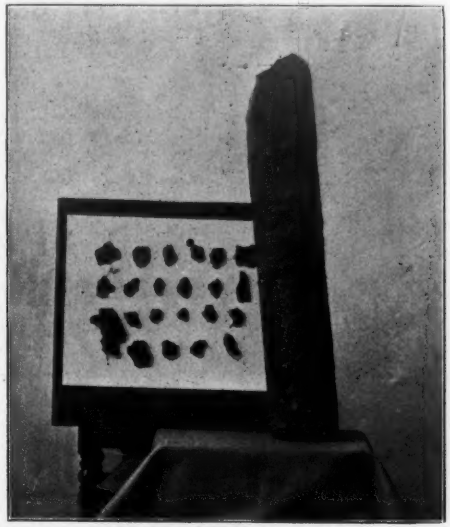


FIG. 3. — DESTRUCTION OF WATER MAINS IN DAYTON, OHIO.

Doubtless you are all familiar with the fact that a pipe line which is electrically positive to the return conductor of the electric railway is in a very dangerous electrical condition, and trouble is sure to result sooner or later. Lead has been destroyed under an electrical pressure of 0.01 volt, and cast iron under 0.5 volt. Notwithstanding this, some theoretical writers still say that "cast iron, particularly those varieties that contain large amounts of carbon and silicon, known as white cast iron, are so little affected as to be almost exempt." As a matter of fact, a cast iron water pipe in Dayton, Ohio, 3 800 feet from the power house, was so affected as to be softer than lead. (See Fig. 1, Plate II). Indeed, the destruction to gas and water pipes throughout the West is enormous, and there is little prospect of any improvement in the conditions.

It appears that all of the methods employed by the single trolley electric roads have proved failures. Ought we now to remain quiet while they experiment with a thousand and one other and equally as unsatisfactory arrangements? The street railway companies have not invested and, it seems probable, will not invest the necessary capital to fully protect the pipes unless forced to do so. It is the part of wisdom in a water works manager to insist upon the removal of these dangerous currents from his pipes as soon as electrical tests show them to be present, and not to wait until their destructive effects are proved by serious damage to the mains.

DISCUSSION.

Mr. Charles H. Morse* (by letter). I have read with much interest the paper of Mr. Brownell. There can be no doubt that the single trolley street railways are working great injury to the underground pipe systems of our cities. In order to reduce this danger to a point which should be tolerated, an immense amount of return wire must be installed.

I have just learned that in the city of Washington, D. C., the government has taken a wise stand, and has compelled the railway companies to install a complete metallic circuit, — a double trolley system. The suggestion has been made that a three wire system, so called, might be used, — that is, have part of the system connected so that the trolley would be positive to the earth and another section negative; by making these zones of small area the ground

* Cambridge, Mass.

would be neutral and the pipes and rails would carry little current. The Edison Lighting Companies use this system for incandescent lighting, and make a great saving in copper.

Something must be done, and will be, if not voluntarily, then through legislative action; but not until hundreds of thousands of dollars' worth of pipe have been destroyed.

A double trolley system will completely remedy the evil.

Mr. W. E. Foss * (by letter). The large main pipes of the Metropolitan Water Works traverse nearly all of the cities and towns located within ten miles of the State House in Boston. During the past four years, while laying these mains, very favorable opportunities have been presented to study the subject of electrolysis, and to learn much from experience about the stray currents of electricity from the street railways, — the currents causing the electrolytic action which is stealthfully destroying the underground piping systems.

As a result of this study and experience it is my opinion that it is good practice to keep the pipes as much isolated from the rails and return circuits as possible, as suggested by Mr. Brownell. I believe, however, that the main object should be to keep the stray electric currents out of the ground.

The electrical resistances given for the several pipe lines are of much interest. It would also be interesting to know about the method of measurement by which the resistances were obtained.

When the study of this subject was begun on the Metropolitan Water Works, in the fall of 1896, it was seen that a knowledge of the electrical resistances of pipe lines of various diameters would be of value. Measurements to determine these resistances have been made at all favorable opportunities.

Although the resistances of pipe lines in which no attempt has been made to obtain a uniform electrical contact at the joints vary largely in different lines of the same diameter, and even in different portions of the same line, the results which have been obtained on the Metropolitan Water Works may be of interest. They are as follows: —

* Assistant Engineer, Metropolitan Water Works.

ELECTRICAL RESISTANCE OF CAST-IRON PIPE WITH LEAD JOINTS.

Diameter of Pipe. (Inches.)	Resistance. Ohms per 1 000 feet. (Approximate.)	Remarks.
12	.021	New pipe, never filled with water.
16	.027	" " " " " "
16	.060	Full of water, in use 6 months.
20	.020	" " " "
24	.028	Empty, in use 18 months.
36	.012	New pipe, never filled with water.
36	.029	" " " " " "
36	.035	" " " " " "
48	.004	" " " " " "
48	.016	Full of water, in use 6 months.
48	.018	New pipe, never filled with water.

All the measurements were made on the pipes as laid in the ground. The method of measurement was in all cases to cause a measured quantity of electricity to flow to or from the pipe, and measure the drop in the voltage occurring in a known length of the pipe line. The quantities of electricity used in making these measurements varied from 10 to 140 ampères.

While laying pipe lines, currents of electricity of from 20 to 100 ampères have been obtained by connecting the ends of sections with a No. 8 copper wire before the sections were united. At the point where the largest current was measured, a wire nail one tenth of an inch in diameter was heated to a white heat when placed between the ends of the 48-inch pipes before the sleeve used in making the closure was put on. These facts give us an idea of the magnitude which has already been reached by the stray electric currents from the street railways.

It is with much interest that I learn that it is the opinion of an electrical engineer that it is questionable whether a single trolley electric railway system, in a city as large as Detroit, can ever be provided with a satisfactory return circuit without incurring an expense sufficient to completely install an insulated return circuit. My own experience and study have convinced me also that such is the case.

I have in mind a district containing about 800 000 inhabitants, in which the average current supplied to the street railway system is about 15 000 ampères, and reaches a maximum at times during the day of 20 000 ampères in summer and possibly 50 000 ampères in

winter. As a return path for this current there is as much as 250 miles of single track, laid with heavy rails thoroughly bonded, and in addition probably the equivalent of 200 miles of copper cables with a sectional area of 500 000 circular mills. In the portions of this district most remote from the power stations the rails are from 6 to 10 volts positive to the large water pipes, and from 2 to 3 volts positive to the smaller pipes. Near the power stations the pipes are positive to the rails by about the same amounts.

Can this dangerous condition be remedied by the method which is receiving the most attention at the present time, that of providing additional return paths for the current?

Assuming that the 250 miles of single track are equivalent to 1 000 miles of copper cable with sectional area of 500 000 circular mills, to double the present return system would require 1 200 miles of such cable, which would cost about $2 000 000. As a result of this outlay, the difference in potential between tracks and pipes would probably be reduced to about one half of the differences existing under present conditions. Would this result be considered a satisfactory solution of the problem? All that would have been gained from the outlay of this large sum of money would be that the danger had been moderated to some extent.

It appears that the acute danger can be somewhat relieved by this method, but so long as the current is allowed to be discharged freely into the earth in such large quantities, it is not practicable to prevent electrolysis completely in this way.

Mr. Brownell's opinion in regard to an insulated return system would be of interest. Is it practicable to install and operate such a system for a city of 500 000 inhabitants?

The high resistance of the cast-weld joints obtained by Mr. Brownell is remarkable. I am informed that the resistance of this bond where it has been put in properly in cold weather is no greater than that of the rail.

Mr. E. E. Brownell (by letter). Since reading the foregoing paper, various questions have been asked, especially about the resistance in ohms of the various-sized piping systems and joints, which, with other accompanying data, will perhaps be of much interest.

The electrical resistance of any piping line, in streets with other parallel conductors, such as gas and water mains, with their service pipes, can never be obtained to any marked degree of accuracy. Moreover, the resistances of gas mains of like material and size are

from 10 to 15 per cent. higher than those of water mains. The resistance of the earth surrounding the mains is an important factor in increasing or reducing the resistance of any piping line having lead joints; so is the character of the lead joint, where affected by electrolytic action.

Having very recently had occasion to remove a section of a water main, partially destroyed by electrolytic action, I found that 17 out of 19 joints were leaking very badly, showing a resistance of 22 per cent. higher than similar pipe not thus affected by electrolytic action.

The following tests have been carefully made at the expense of considerable time and money in securing conditions so as to get as accurate results as possible.

The current supply was taken from accumulators, using duplicated Weston instruments, just calibrated, and the most delicate manufactured. These pipes were *completely* isolated from any other conductors, and remote from any electrical influence of any kind, even to the grounding of a single telephone, the earth, which was a dry gravel soil, being the only variable included in the following tests. The pipes had been laid from five to ten years.

TABLE SHOWING AVERAGE ELECTRICAL RESISTANCE, ETC., IN CAST IRON PIPES OF VARIOUS SIZES.

Diameter of Pipe. (Inches.)	Loss of Electrical Pressure. (Volts.)	Quantity of Current. (Amperes.)	Electrical Resistance per 1 000 feet of Pipe. (Ohms.)
4	14.72	8.	1.84
6	8.89	11.2	.792
8	5.35	12.4	.432
10	3.32	12.1	.275
12	2.46	13.2	.187
16	1.26	12.2	.104
18	.988	12.2	.081
20	.819	12.6	.065
24	.504	11.8	.045
28	.369	11.1	.033
30	.319	11.0	.029
36	.168	11.2	.015

The above results are each the average of a series of ten independent tests, the greatest variation being less than four per cent. in each series of ten readings; while the readings in a crowded street, with many other piping lines adjacent, varied from 20 to 300 per cent. in resistances.

All information upon this subject should come only from practice, otherwise it is worthless and only tends to mislead the public. Far

too much theory has already been submitted, with few or no facts to substantiate its correctness.

Local conditions cause different results in every city, or upon every piping line, so no specific rule will hold good in all cases, while a general one may.

In conclusion, it is my opinion, after having carefully tested over 187 systems, that the evils of electrolysis could be avoided with little difficulty, providing the necessary outlay of capital was allowed. Without this we must expect to submit to the great deterioration due to these stray currents, for years to come.

PROCEEDINGS.

QUARTERLY MEETING.

YOUNG'S HOTEL, BOSTON, March 14, 1900.

President Cook in the chair.

The following members and guests were present: —

MEMBERS.

Charles H. Baldwin, Roland D. Barnes, James F. Bigelow, Lewis M. Bancroft, Frank A. Barbour, Joseph E. Beals, E. C. Brooks, James W. Blackmer, George F. Chace, G. L. Chapin, John C. Chase, Henry A. Cook, Byron I. Cook, Freeman C. Coffin, J. W. Crawford, A. O. Doane, B. R. Felton, John N. Ferguson, Z. R. Forbes, F. F. Forbes, Julius C. Gilbert, J. F. Gleason, W. E. Foss, J. A. Gould, Frederick W. Gow, E. H. Gowing, William R. Groce, E. A. W. Hammett, John C. Haskell, William E. Hawks, Horace G. Holden, F. S. Hollis, Frank E. Hall, F. G. Judkins, Willard Kent, Leonard P. Kinnicutt, Morris Knowles, James W. Locke, A. E. Martin, Leonard Metcalf, F. E. Merrill, Thomas Naylor, Horatio N. Parker, John N. Perkins, J. B. Putnam, A. H. Salisbury, Charles W. Sherman, J. A. St. Louis, George A. Stacy, Walter H. Sears, John D. Shippee, H. O. Smith, Solon F. Smith, William F. Sullivan, Lucian A. Taylor, Robert J. Thomas, William H. Thomas, Harry L. Thomas, D. N. Tower, George W. Travis, W. H. Vaughn, William W. Wade, Charles K. Walker, George E. Winslow, C. J. Youngren.

ASSOCIATE MEMBERS.

Chapman Valve Mfg. Co., by George F. Hughes; M. J. Drummond, by Walter J. Drummond; Hersey Mfg. Co., by Albert S. Glover; Henry F. Jenks, Pawtucket, R. I.; Neptune Meter Co., by H. H. Kinsey; Rensselaer Mfg. Co., by Fred S. Bates; A. P. Smith Mfg. Co., by W. H. Van Winkle; Union Meter Co., by Frank L. Northrop; Walworth Mfg. Co., by B. Frank Polsey; The George Woodman Co., by H. A. Gorham.

GUESTS.

V. G. Barnard. Purch. Agent, Lowell, Mass.; Amos H. Eaton, Chairman, Middleboro, Mass.; John Greenleaf, Auburn, Me.; H. R. Johnson, Reading, Mass.; Leigh T. Macurdy, Watertown, Mass.; D. P. Mansur, Everett,

Mass.; R. A. Sears, Ex-Mayor, Quincy, Mass.; Everett U. Crosby, New York City; D. W. Cole, Melrose, Mass.

The following new members were elected: —

Resident Active. — D. W. Cole, Melrose; Frank E. Fuller, West Newton, Engineering Department Metropolitan Water Board.

Non-Resident Active. — Everett U. Crosby, of the North British Mercantile Insurance Co., of New York; Thomas H. Bennett, Superintendent Oswego Water Works, Oswego, N. Y.

Associate. — Henry N. Libbey, Boiler and Water Works Supplies, and manufacturer of the Libbey Drip Valve, Boston.

On motion of Mr. Holden, the President was requested to appoint a committee to nominate officers for the ensuing year, to report at the next regular meeting. The President announced that he would appoint the committee at some future time.

The President appointed as a committee on revision of the Constitution suggested by past President Forbes, to report at the September meeting, past President George A. Stacy, Charles W. Sherman, and Albert S. Glover.

On motion of Mr. Morris Knowles, the selection of the place for holding the next annual meeting was referred to the Executive Committee with full power.

On motion of Mr. Sherman, the thanks of the Association were extended to Mr. Forbes for the opportunity afforded to visit Brookline and witness his process of making cement-lined service pipe.

The first paper of the afternoon was by Everett U. Crosby of the North British Mercantile Insurance Co., of New York, his subject being "Eliminating the Conflagration Hazard." The paper was discussed by President Byron I. Cook and Messrs. E. C. Brooks, John C. Chase, J. C. Gilbert, George F. Chace, J. A. Gould, H. G. Holden, and R. J. Thomas. On motion of Mr. Holden, the thanks of the Association were voted Mr. Crosby for his paper.

Mr. J. C. Haskell, Superintendent of Water Works, Lynn, Mass., read a paper on "Public Water Systems *vs.* Typhoid Fever," which was discussed by Prof. L. P. Kinnicutt, Mr. George F. Chace, Dr. F. S. Hollis, and Mr. Morris Knowles.

Mr. Freeman C. Coffin, Civil and Hydraulic Engineer, of Boston, read a short paper entitled "A Few Notes on Cast Iron Water Pipe." It was discussed by Mr. John C. Chase.

Mr. C. W. Sherman read a paper by William Murdoch, Engineer and Superintendent of Sewerage and Water Supply, St. John, N. B., on "Wooden Joints in Cast Iron Water Mains."

Adjourned.

EXCURSION.

Previous to the meeting of March 14 a number of the members visited Brookline at the invitation of Mr. F. F. Forbes, Superintendent of the Brookline Water Works, to witness his process of lining service pipes with cement, which was described at the February meeting.

OBITUARY NOTE.

NATHANIEL DENNETT, for twenty-two years Superintendent of the Somerville, Mass., Water Works, died at his home in that city on February 21, 1900, from the effects of a stroke of paralysis. He was born in Portsmouth, N. H., January 26, 1828. During the Civil War he served as a member of Company B, 5th Massachusetts Volunteers. He was elected a member of this Association on September 19, 1883.